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# POST-GLACIAL LAKES IN THE MACKENZIE RIVER BASIN, NORTH WEST TERRITORIES, CANADA

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It is a well-known fact that lakes or ponds of impounded water would form whenever the retreating continental ice sheet receded down a stream valley. It is therefore evident that the run-off from the eastward slopes of the Rocky Mountain cordillera would be impounded behind the retreating ice front of the Keewatin glacier as it receded, and the lakes so formed would expand laterally along the margin of the ice sheet, and the water would collect both from the inflowing streams and the melting ice until it rose above the lowest point in the stream valley walls, when it would spill over and form a new river course, possibly at considerable variance to the pre-established drainage lines. Thus we would expect to find evidence of ice-dammed lakes of greater or less magnitude throughout large areas in the northern portions of the great plains area of the Dominion of Canada. It is not the object of this paper to deal with the possible extent of such lakes throughout the northern regions, but rather to consider one or two specific stages in the lake expansions as they were apparently developed in the lower Peace and Athabaska river valleys, Athabaska Lake and Great Slave Lake.

The area to be discussed is shown in the accompanying map (Fig. 1). It lies between latitudes 56° north and 63° north, longitudes 107° west and 120° west, and it comprises the lower portions of the valleys of Peace and Athabaska rivers, Athabaska Lake and Great Slave Lake.

Tyrrell,[1] in his report on Athabaska Lake and Churchill River, makes frequent reference to the great post-glacial lakes of this region. He says:

> North of the watershed between Churchill and Stone rivers, most of the akes appear to have stood at a higher level than they do at present, in the time immediately subsequent to the retirement of the great ice-sheet. The natural inference is that they lay between the face of the waning ice-sheet and higher land over which the water flowed to form the great rivers of the glacial period.

He proposed the addition of the prefix "hyper-" to the name of the present lake or river to designate the former high-level lake that occupied its basin or valley.

Tyrrell's report covers the area east of Athabaska River and south of Athabaska Lake, and is therefore in part included in the region under discussion. Certain parts of his reports are of prime importance in any consideration of the question. Particular reference must be made to his Hyper-Black Lake, Hyper-Athabaska Lake, and Hyper-Churchill Lake. Black Lake lies directly east of the eastern extremity of Athabaska Lake and is connected with Athabaska Lake by a broad, trenchlike valley at present occupied by Stone River. Tyrrell says:

> Hyper-Black Lake stood 125 feet above the present level of Black Lake, and extended for a long distance up Cree and Stone rivers. Hyper-Athabasca Lake rose above the present level of Lake Athabasca, as is shown by the beautiful raised beaches on Beaver-lodge Island, and the wide sandy plains seen by Mr. Dowling on William River; but whether it at any time was confluent with Hyper-Black Lake was not determined. . . . . Hyper-Churchill Lake lay in the present valley of Churchill River, and, when at its greatest height, seems to have extended southward as far as the sand-hills around Clearwater Lake on the Green Lake trail.

[1] J. B. Tyrrell, "Athabasca Lake and Churchill River," *G.S.C. Annual Report*, New Series, Vol. VII, "D," 1895.

From a perusal of Tyrrell's report it is possible to outline at least one main drainage channel of the great post-glacial lakes that is of particular importance to our problem.

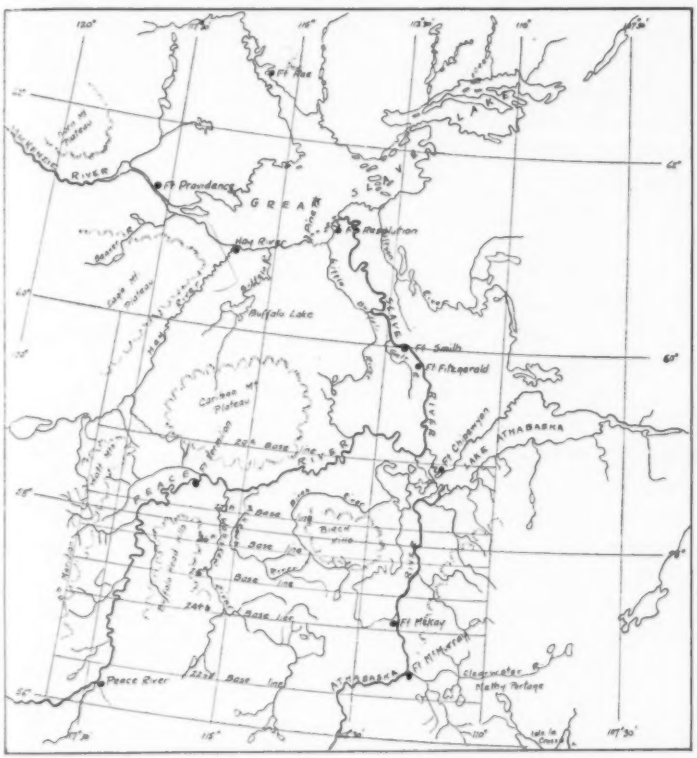


FIG. 1.—Map of portion of Mackenzie River basin, showing lower portions of Peace and Athabaska river valleys and basins of Athabaska Lake and Great Slave Lake. Scale, 1 inch = 117 miles.

This channel appears to connect with the Clearwater River valley at Methy portage, following it southeast through Buffalo Lake, Isle la Crosse Lake, Beaver River, Green Lake, Big River, and Shell Creek to the valley of the Saskatchewan. It is reported as a broad, trenchlike valley with the watershed between the Saskatche-

wan and Churchill rivers lying in a sandy plain at the bottom of the deep valley. As will be shown later, a portion of this valley probably at one time was the principal drainage channel of great post-glacial lakes lying in the Athabaska and Peace river valleys, though possibly Hyper-Churchill Lake intervened to take the waters from Hyper-Athabaska Lake before discharging them into the Saskatchewan River.

A second channel is suggested in his account of the east end of Athabaska Lake and the valley of Stone River below Black Lake. This appears as a short, narrow channel connecting the waters of Hyper-Athabaska Lake with those of Hyper-Black Lake. It would seem very probable that during a certain period of the lake formations these two bodies of water were confluent by way of this channel, and that the outlet of the chain of lakes lay possibly by way of Mudjatick River Valley to Hyper-Churchill Lake or by another channel farther east.

Just at the eastern end of Athabaska Lake Tyrrell reports two distinct sets of glacial striae: an earlier one tending south, 65° west, parallel to other striae seen almost everywhere along the shore and doubtless made by the ice sheet from the northeast; and a later one, tending south, 35° west, probably made by a local glacier descending from the high land to the north after the greater ice sheet had withdrawn.

> A portion of the moraine of this later local glacier may be seen as a great stretch of huge broken masses of rock, forming a prominent point, and covering the shore for a considerable distance beyond it. . . . . Athabasca Lake is here five miles wide, and lies in a long narrow valley with a steep sandstone escarpment between 400 and 500 feet high on its south side. The later glacier from the north flowed into the valley at this point, and probably reached across to the south side, completely filling it and damming up the water from the east to the height of the sandstone plain on the south, which is at about the level of the high benches previously described on the banks of Cree River and along the west shore of Black Lake. The occurrence of an ice dam across the valley accounts fully for the former existence of a large lake in the present basin of Black Lake. Without the ice dam, or some other dam of which no evidence can be found, the water of Black Lake could not have stood much above its present level in glacial or post-glacial times, for the great valley of Athabasca Lake, which extends eastward to Black Lake, dates back to a period long before the glacial epoch.

The formation of this dam is important in the consideration of the drainage of the great lakes formed in the Athabaska and Peace river valleys to the west. Tyrrell does not seem to appreciate the fact that for a long period the northward drainage of the Athabaska Lake Valley was blocked, and that consequently the waters of Hyper-Athabaska Lake must have stood high and the natural outlet of these waters would, at one time at least, be by way of Black Lake and the Stone River Valley; and, therefore, the damming would probably have more to do with the closing of a possible outlet of Hyper-Athabaska Lake than the formation of a Hyper-Black Lake. As has been already suggested, the writer believes this damming separated the confluent waters of Hyper-Athabaska and Hyper-Black lakes, allowing the rapid drainage of the smaller Hyper-Black Lake eastward, while the water still remained high in Hyper-Athabaska Lake.

## PEACE RIVER VALLEY

If one stands on the plain level above the town of Peace River, an extended view both up and down the valley of the Peace is available. The strikingly flat character of the plain level is apparent, and, if one could extend his vision, he would be struck by the similarity of elevation between the level on which he stands and that of the high lands lying to the north and the east. The elevation of the plain at Peace River is 2,250 feet above sea-level. That of the Watt Mountains is about 2,700 feet, and that of the Eagle Mountains is about the same. Caribou Mountain Plateau is slightly higher. The summit on the twenty-ninth base line is 3,225 feet, and to the northward the elevations probably average over 3,500 feet. Buffalo Head Hills and the Birch Hills average about 2,700 feet, and the plain level at the end of steel on the Alberta and Great Waterways, sixteen miles from McMurray, is 2,500 feet. This similarity of elevation is conspicuous, and can only point to the fact that these present outlying plateaux were in recent geological times connected and formed a continuous plain of fairly uniform relief.

At Peace River, the valley of the Peace is both broad and deep, and yet it is evidently well filled by the river it contains. Here

is no river flowing sluggishly in a valley much too large for itself, but a mighty stream which, still in its youth, has carved and is still carving a valley in just proportion to its size.

On descending the river below the town, the valley walls contract to gorgelike proportions, and the apparent crest of the valley gradually lowers. Ascending to the crest at a point some 50 miles below Peace River, one would find himself on another plain level at a lower elevation than that above Peace River town.

The plain is narrowed to a width of about 50 miles, but is distinctly flat. It is bordered on the east by the shoulder of Buffalo Head Hills, and on the west by a southerly extension of the Watt Mountain Plateau. The elevation of this plain is about 1,600 feet.

Descending the river still farther to a point near Battle River and there scaling the immediate valley walls, another plain level confronts the eye on reaching the top, this time at an elevation of 1,100 feet. East or west from the river this plain stretches some thirty to forty miles before rising gradually to a comparatively narrow bench land at an elevation of about 1,600 feet which must be crossed before ascent can be made to the old, original plain level.

About 50 miles above Vermilion the Peace River swings rapidly eastward and, the valley walls receding, it enters a widely extended plain area at an elevation of about 800 feet which, at Vermilion, stands scarcely more than 30 feet above water level. This plain level is practically continuous with the basin of Athabaska Lake and extends northward around the foot of Caribou Mountain Plateau to the basin of the Great Slave Lake.

### WABISKAW AND ATHABASKA RIVERS

Strikingly similar features to those outlined above are to be found in the valleys of the Wabiskaw and Athabaska rivers to the east. These are well brought out in the profiles of the base, lines and meridians of the Dominion Topographical Surveys as shown in the accompanying sketches (Fig. 2).

The 1,600-foot level shows as the broad plain south of Hay River on the sixth meridian; distinctly on the shoulder of Caribou Mountains on the twenty-ninth base line; on both slopes of Birch Hills on the twenty-seventh base line; on both sides of the

valleys of the Peace and Wabiskaw rivers on the twenty-sixth; on the Peace, Athabaska, and Wabiskaw valleys on the twenty-fifth; slightly on the Peace and Athabaska rivers on the twenty-fourth base line and just faintly on the east side of the Athabaska River on the twenty-second base line.

The 1,100-foot level shows on the northern half of the broad plain of Hay River on the sixth meridian; throughout the greater

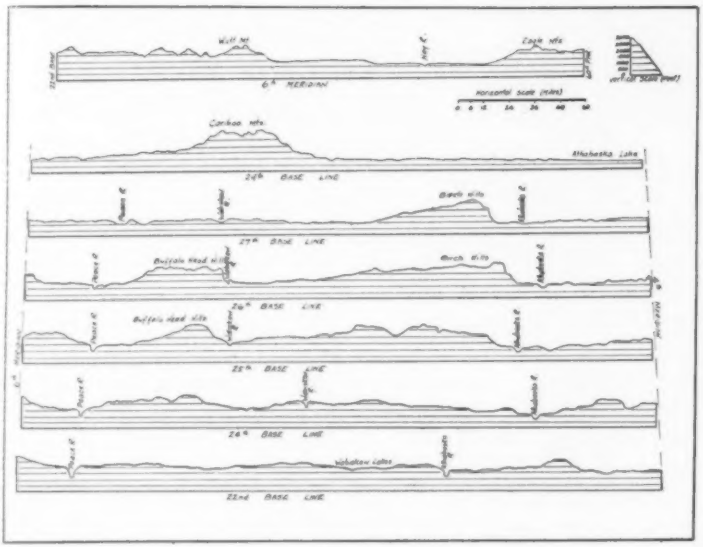


FIG. 2.—Profiles of base lines and meridians of the Dominion Topographical Surveys, Department of Interior.

part of the twenty-seventh base line; somewhat on the Peace River and very pronouncedly on the Athabaska River on the twenty-sixth base line; and on the Athabaska River only on the twenty-fifth base line.

The 800-foot level shows between the fourth and fifth meridians on the twenty-ninth base line; and in two places on the twenty-seventh base line—the valley of Athabaska River, and near the fifth meridian.

### HAY AND BUFFALO RIVERS

A trail leads overland from Vermilion, on Peace River, to Hay River. For about 80 miles northwest from Vermilion it traverses a flat plain at an elevation of about 800 feet above sea-level. It then crosses a low divide, the summit being at 1,500 feet, and enters the long, narrow plain area in the center of which flows Hay River. The elevation of this plain at its upper end is about 1,100 feet. Hay River follows this plain in a northeasterly direction for 150 miles, dropping scarcely more than two feet to the mile, until, within 50 miles of its mouth, it falls abruptly over an escarpment into the basin of Great Slave Lake, forming Alexandra Falls (Figs. 3 and 4).

FIG. 3.—View of Alexandra Falls, Hay River, N.W.T., looking upstream. (Photo by A. E. Cameron, 1916.)

FIG. 4.—View of Alexandra Falls, Hay River, N.W.T., showing close view of escarpment. (Photo by A. E. Cameron, 1916.)

### SLAVE RIVER

At Fort Smith the Slave River cuts through a poorly developed escarpment some 125 feet high. The crest of the escarpment shows distinct evidence of the shore-line conditions in the form of well-developed sand dunes and a flat horizon to the north and east. West of Fort Smith at

Salt River an abandoned lake basin is distinctly shown in the salt plains lying at the foot of an escarpment facing east (Figs. 5 and 6). The plains are for the most part void of vegetation and form a broad flat, water-soaked in the wet season and salt-incrusted in the dry. Shore-line conditions are shown by narrow spruce- and

FIG. 5.—View of the salt plains on Salt River, west of Fort Smith, N.W.T. (Photo by A. E. Cameron, 1920.)

FIG. 6.—Another view of the salt plains on Salt River, west of Fort Smith, N.W.T. (Photo by R. T. Hollies, 1920.)

poplar-clad points jutting out from the irregular face of the escarpment into the clay flats, bordered frequently by bowlder pavements or shingle beaches. Low off-shore islands showing water-deposited material are also noticeable (Fig. 7). The Salt River escarpment

follows north down the west side of Little Buffalo River for about 30 miles and then gradually disappears to the west.

### GREAT SLAVE LAKE

Great Slave Lake lies at an elevation of about 500 feet above sea level. The south shore of the lake near Pine Point, west of

FIG. 7.—Small island in salt plains, west of Fort Smith. Salt spring deposits in foreground. (Photo by A. E. Cameron, 1920.)

FIG. 8.—Wave-cut limestone bluff at elevation of 200 feet above Great Slave Lake. (Photo by R. T. Hollies, 1920.)

Resolution, rises rather steeply for a few miles, showing storm-built beaches of limestone shingle, to a limestone bluff at an elevation of about 700 feet (Fig. 8). Inland lies a rolling country which rises gradually to the south. Each roll shows limestone shingle beaches and bowlder pavements, and not a few are topped by sand dunes.

Each roll may be traced eastward to where it pinches out into the hollows between. The trend of these rolls conforms closely with the direction of ice movement as established by glacial striae at various points along the lake shore. Each roll can only represent a point, carved out by the glacier when it was excavating the basin, around which the waters of the lake lapped at some stage in its development.

FIG. 9.—View of shingle beach, at elevations up to 150 feet above present lake level, Great Slave Lake, N.W.T. (Photo by A. E. Cameron, 1916.)

FIG. 10.—View of shingle beach, at elevations up to 150 feet above present lake level, Great Slave Lake, N.W.T. (Photo by R. T. Hollies, 1920.)

Elsewhere about the lake shores undoubted lake beaches and wavecut cliffs are observable at various elevations above the present lake level. They are very numerous and excellently well developed, and are noticeable wherever high land exists in the vicinity of the present shore line (Figs. 9 and 10).

### TERMINAL MORAINES

In the valleys of Hay and Buffalo rivers occur terminal moraines, marking positions of the ice front during stages of halt or of slight

re-advance of the ice sheet during the general retreat from the region. The moraines consist of low ranges of irregularly shaped hills, somewhat higher in elevation than the adjacent country, and trend in a general direction at right angles to the movement of the glacier, as shown by glacial striae. The best-developed moraine occurs immediately north of Buffalo Lake. The morainic hills here have an elevation of 200 to 300 feet above the surrounding country, and form a dam behind which the waters draining from the north slopes of Caribou Mountains are ponded, forming the large shallow body of water known as Buffalo Lake. This moraine extends north to within a few miles of Great Slave Lake. Two moraines were noted in the valley of Hay River; one tending to connect the Watt Mountain Plateau with that of Eagle Mountains; and the other, the Caribou Mountains with Eagle Mountains. The low ridge of glacial drift now existing between Watt and Caribou mountains and forming the present watershed between Peace and Hay rivers appears to be an interlobate moraine formed between two lobes of the waning glacier.

### PROBABLE LAKE EXPANSIONS

From this somewhat scanty evidence an attempt may be made to outline the various stages of lake formations developed as the continental ice sheet retreated from the region.

At least three definite glacial lobes are apparent in the area. One extended up the valley of Hay River; a second swung west, south of the Caribou Mountains, and probably sent tongues up the valleys of the Peace and Wabiskaw rivers; while the third lay in the basin of Athabaska Lake with its tongue pointing up the valley of Athabaska River.

The first stage to be considered (Fig. 11), is when the water level stood at about 1,600 feet. The Hay River lobe extended up the valley to a point south of the sixtieth parallel. The edge of the other lobes is not determinable from the information at hand, but it would appear that the Peace River lobe extended well up toward Vermilion and probably sent a tongue south up the valley of the Wabiskaw to a point close to the twenty-sixth base line; while the Athabaska lobe must have extended at least as far south as this same line. The similarity of elevation of the lake benches

in all the valleys can only point to the fact that the waters were in conjunction with one another. Those in the Hay and Peace river valleys undoubtedly were connected through straits between Caribou Mountains and Watt Mountains. The other connections were apparently by marginal channels along the ice front. Drainage northward by way of the Mackenzie River was blocked, and it

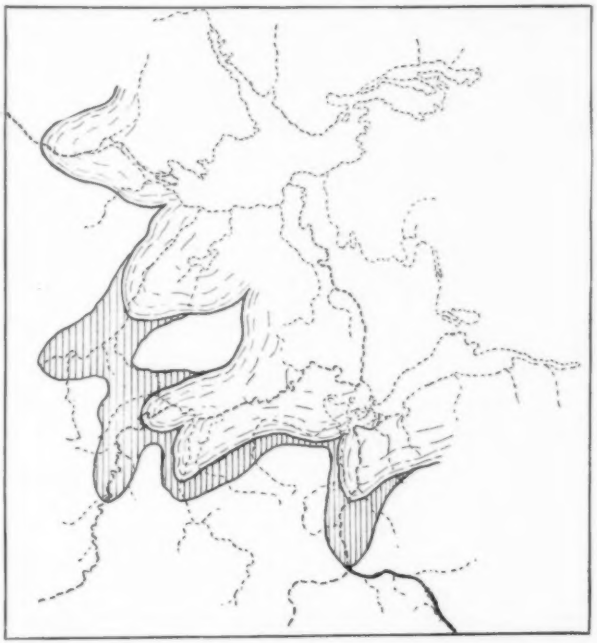

FIG. 11.—Outline map showing probable position of Keewatin ice sheet and lake expansions when the water stood at the 1,600 foot level.

seems likely that the lake in the Athabaska Valley was somewhat lower in level than the others, and may have been drained eastward toward Hudson's Bay. The more probable outlet, however, was by way of the Clearwater River and Methy portage to the Churchill River Valley. The summit of Methy portage is 1,735 feet above sea-level—scarcely more than 200 feet higher than the lake level at that stage. This difference could easily be accounted for by

differential elevation of the land following the retreat of the ice front.

In the second stage (Fig. 12) the water level stood at about 1,100 feet. The Hay River ice had retreated to the morainal ridge north of Buffalo Lake and the Peace and Athabaska lobes had similarly retreated. Drainage down the Mackenzie was

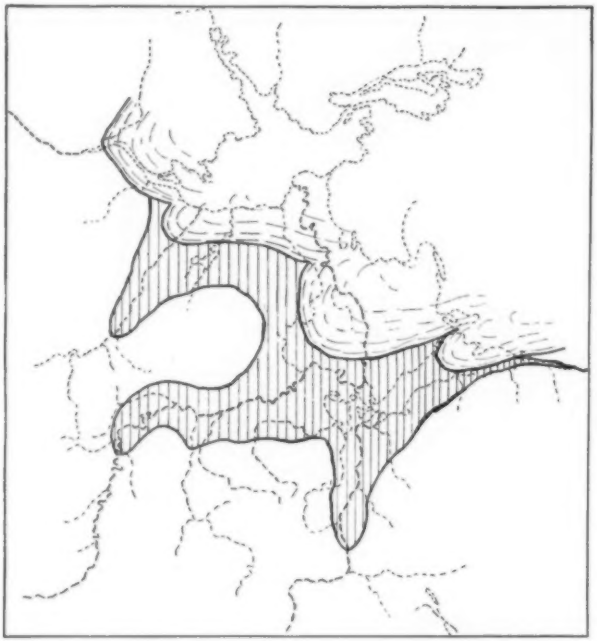

FIG. 12.—Outline map showing probable position of Keewatin ice sheet and lake expansions when the water stood at about the 1,100 foot level.

still blocked, the lake basins were all continuous, and outlet must have been by way of Fond du Lac on Athabaska Lake, in the long, extended arm of that lake, and thus eastward, probably by way of Churchill River.

The Mackenzie River outlet must have been cleared soon after, but was apparently blocked farther north, for we find the water level standing at 800 feet and developing beaches on all sides of

the present shore line. At the 800-foot elevation (Fig. 13) the ice had receded clear of Athabaska Lake and practically clear of Great Slave Lake, though a small tongue remnant of the Great Slave Lake lobe may have occupied the eastern extension of the lake. The water level was well below the Fond du Lac outlet on Athabaska Lake, but the Mackenzie Valley was open and drainage

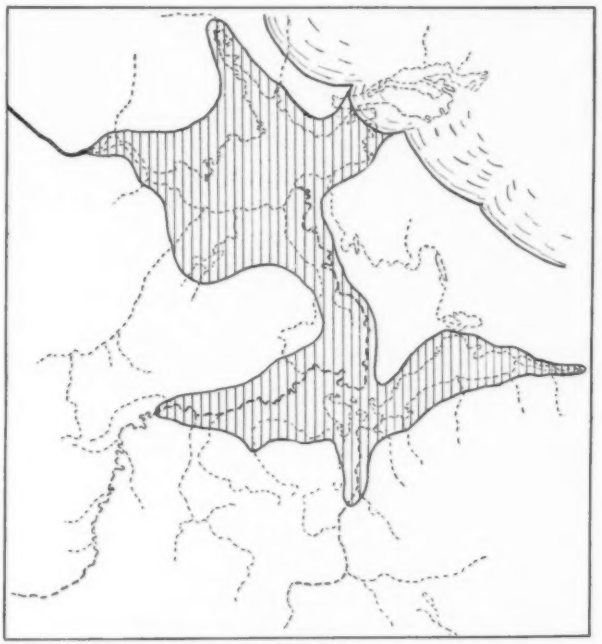

FIG. 13.—Outline map showing probable position of Keewatin ice sheet and lake expansions when the water stood at about the 800 foot level.

should have been that way. The two main basins are continuous by means of a narrow strait across the low escarpment at Smith. The Great Slave Lake basin was expanded to take in the present basin of Buffalo Lake, though probably low morainal islands marked the position of the morainal ridge north of Buffalo Lake.

On the retreat of the ice, isostatic readjustment of the land areas took place, with a raising of the land in a series of differential

elevations to the north and east, possibly on successive hinge lines. The area south of McMurray was probably differentially raised, causing elevation of the Methy portage outlet, and, later, movements developed in the neighborhood of Fort Smith, raising a land barrier there about 125 feet high, and causing a separation of the two basins (Fig. 14). We thus find two large bodies of

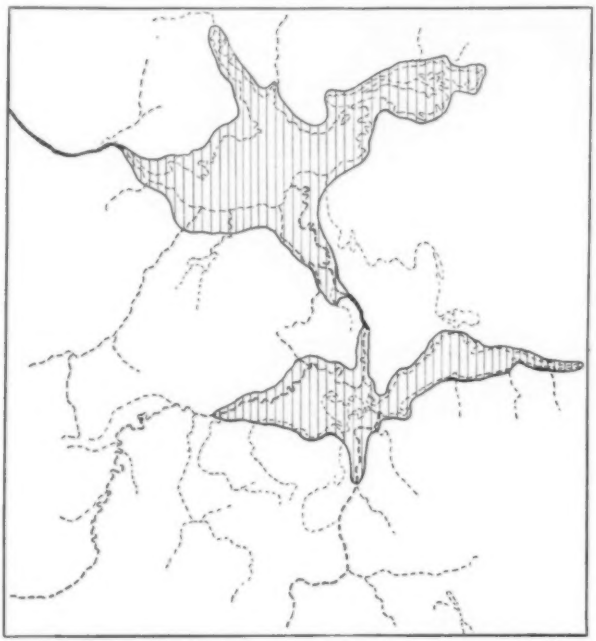

FIG. 14.—Outline map showing probable lake expansion when water stood at the 700 foot level.

water existing in the separated basins: Athabaska Lake, standing at about 750 feet, and Great Slave Lake at some 600 feet.

The two basins have acted very differently since their separation. Isostatic readjustment north of Athabaska Lake has tended to close the outlet, keeping the waters ponded back, and drainage has been accomplished by Slave River cutting its channel as fast as the ground rose. As a consequence the water level has dropped

only slightly since that time. The level of Athabaska Lake is now 699 feet above sea-level at average water conditions.

Northward, however, conditions are very different. The outlet of the basin lies at its western corner, and differential elevation to the north and east has only had the effect of spilling more water down the Mackenzie River, with the result that the basin has been rapidly drained. The rapidity with which the water level fell on Great Slave Lake is excellently well shown in the storm or seasonal beaches found on the forelands, particularly along the north shore. At one place on Windy point over 100 such beaches are observable in an elevation of some 250 feet, and the crest of the hill is marked by a horseshoe beach developed as the ground rose above the water level. The beaches are of fairly uniform depth, and throughout most of the rise occur as a series of very regular waves, indicating that elevation has been at a constant, uniform rate. That movement is still going on is apparent from the beach lines built up in recent times.

In conclusion, the writer can only admit that these are wide generalities based on very insufficient data, and undoubtedly will bear much correction. He feels sure, however, that the outlines suggested are at least approximately correct. Much work has yet to be done, and detail work on the problem would yield many points of scientific interest. One main problem that presents itself is the study of the Great Slave Lake shore lines with a view to determining the time period since the last glacial age. Dr. A. P. Coleman produced[1] much interesting information on this subject by a detail study of raised beaches, delta deposits, and lake bars on Lake Ontario. The seasonal beaches of Great Slave Lake, studied in detail, would give similar information. The Alexandra Falls on Hay River have receded 6.5 miles since their original development—a distance almost equal to that of Niagara Falls. Slave River has completely filled up the long, southward-extending arm of Great Slave Lake, and is still building rapidly into the present lake. The rate at which alluviation is taking place could be readily determined, and an excellent time record seems available.

December, 1921

[1] A. P. Coleman, *Proceedings of the International Geological Congress, Toronto, Canada, 1913.*

# DINOSAUR TRACKS IN HAMILTON COUNTY, TEXAS

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Attention has been called by E. W. Shuler to the occurrence of dinosaur tracks in the Glen Rose limestone of Lower Cretaceous age, near the town of Glen Rose, Somervell County, Texas.[1] Another interesting occurrence of similar tracks has recently come to light in the extreme southern portion of Hamilton County, Texas, about sixty miles south-southwest of the first-mentioned locality (Fig. 1).

The tracks in Hamilton County are also in limestone belonging to the Glen Rose formation. They are exposed in the bed of Cottonwood Creek (Fig. 2), a small headward tributary of Lampasas River, and are confined to a single stratum of rather soft, compact, yellowish limestone about a foot thick, which for a distance of probably 800 feet makes the bed of the creek. In the Glen Rose locality the tracks were evidently made by one individual moving continuously in the same direction; but in Hamilton County they were made by a number of individuals, and the tracks point in every direction of the compass, this spot seemingly having been a favorite haunt of dinosaurs of every size and presumably, also, of every age.

The examination upon which these notes are based was made hurriedly and without adequate means properly to clear the creek bed of the accumulated débris. Normally this portion of the bed of Cottonwood Creek is covered with several feet of water, but the unusually dry summer season of the past year offered a favorable opportunity to examine the footprints, since the creek was free from running water; but it developed that cattle which frequent the water holes along the creek had worked down shale and gravel from the banks in such quantities that almost the entire surface

[1] *Amer. Jour. Sci.*, Vol. XLIV (October, 1917), pp. 294–98.

of the rock was covered with mud or sun-baked soil to a depth varying from several inches to as many feet. It was therefore impossible to clean off the rock over more than limited areas in the short time available.

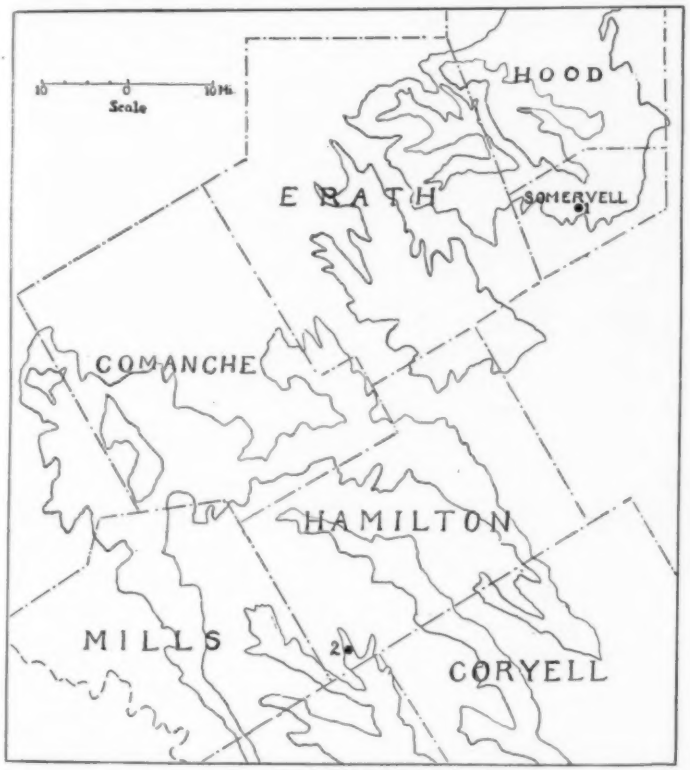



FIG. 1.—Sketch map of a portion of Central Texas showing outcrop of Glen Rose Formation. (After R. T. Hill.) 1, location of Glen Rose tracks. 2, location of Hamilton County tracks.

A spot was selected at random, and the soil was removed from a space about four feet square. Three well-defined tracks were exposed within this space, and four others were less clearly recognizable (Fig. 3). At six other spots the soil and gravel were removed

from patches two to four feet square, and in each instance one or more tracks were found. Some of the tracks were shallow, due to the abrasion of gravel swept over the bed rock by the swift water of freshets, and others were rendered indistinct by superimposed tracks. The creek bed, which is floored with the stratum carrying the tracks, varies in width from four to twelve feet for a distance of about 800 feet. On the basis of the writer's observations, he is convinced that the estimate made by residents of the neighborhood, placing the number of tracks at considerably over a hundred, is not likely to be extravagant. This number could quite likely be considerably increased by clearing away the slumped material along the foot of the caving banks. Reliable parties who have seen the locality when the whole expanse of rock in the creek had been swept clear of its covering state that it exhibits a maze of tracks for fully two-thirds of the foregoing distance. Near the lower or southern end of the rock exposure, where erosion has cut through the level-lying stratum bearing the tracks, a marginal expanse of the limestone on either side of the channel shows that the tracks are infrequent or entirely absent, but northward they are known to be present until the rock disappears under the stream bed.

FIG. 2.—Cottonwood Creek along bed of which dinosaur tracks are found. (Photo by C. B. James.)

The footprints examined varied in length from eight to twenty inches. A plaster cast made by Mr. C. B. James, of Hamilton,

shows the dimensions indicated in Figure 5. This particular track was covered with deep mud at the time of the writer's visit, but enough mud and water was baled out to determine that it was only one of three large tracks within a space of scarcely more than a square yard.

Near the southern end of the locality, where the tracks are infrequent, a single, large, well-formed track three or four inches deep and about fifteen inches long was found. Judging the probable direction of movement from the orientation of the track,

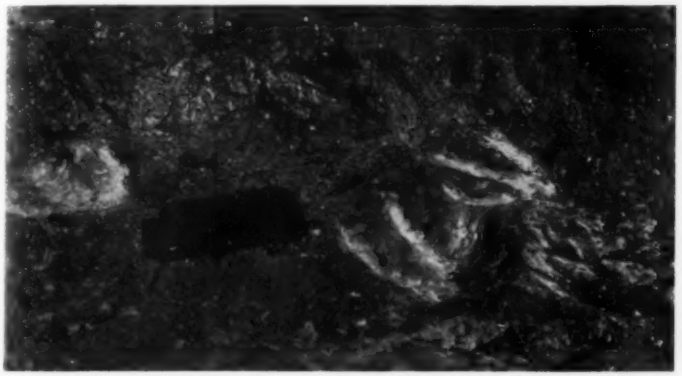


FIG. 3.—Dinosaur tracks in the bed of Cottonwood Creek, Hamilton County, Texas. (The tracks were lightly dusted with white powder to secure definition in the photograph.)

it appeared that other tracks of the same individual should be present on the uncovered rock. Two saucer-shaped depressions were located in the direction of motion, at intervals of about four feet, which were apparently vestiges of footprints, though quite indistinct. The stride of the animal seems therefore to have been about the same as that measured by Shuler at Glen Rose, and the size of the tracks in the two localities corresponds quite closely. This was the only instance in which the stride of a given individual could be measured, though undoubtedly other instances could be found if the rock were adequately cleared of débris.

A correlation of the geologic horizons at which the tracks are found in Somervell and Hamilton counties would be particularly

interesting, but at this time such a correlation cannot be made with any degree of accuracy. Shuler placed the Glen Rose tracks in the middle third of the Glen Rose formation which at that locality has an approximate total thickness of 315 feet.[1] In Hamilton County the interstream divides are capped with basal Edwards limestone containing an abundance of chert. The dinosaur tracks are about 200 feet below the lowest chert bed. Immediately beneath the Edwards limestone are the soft, chalky beds of the

FIG. 4.—Dinosaur track of which dimensions are shown in Figure 5. (Track dusted with white powder.) (Photo by C. B. James.)

Walnut formation, eroded to form a wide, shallow valley, and in the midst of this valley Cottonwood Creek has cut down slightly into the Glen Rose beds. The upper limit of the Glen Rose could not readily be determined in the immediate locality, owing to poor outcrops, but it is tentatively placed about fifty feet above the horizon of the tracks. This tentative correlation is not of much assistance, however, as the total thickness of the Glen Rose is nowhere exposed nearby, and there are no reliable data upon which to postulate thickness in this vicinity. The Glen Rose formation

[1] R. T. Hill, *Twenty-first Annual Report U.S. Geol. Surv.*, Part VII, p. 153.

is probably thicker here than in Somervell County, and northward it thins out and almost completely disappears northwest of Fort Worth, where the Paluxy and Trinity sands, ordinarily separated by the Glen Rose, merge into one thick formation known as Antlers sand.

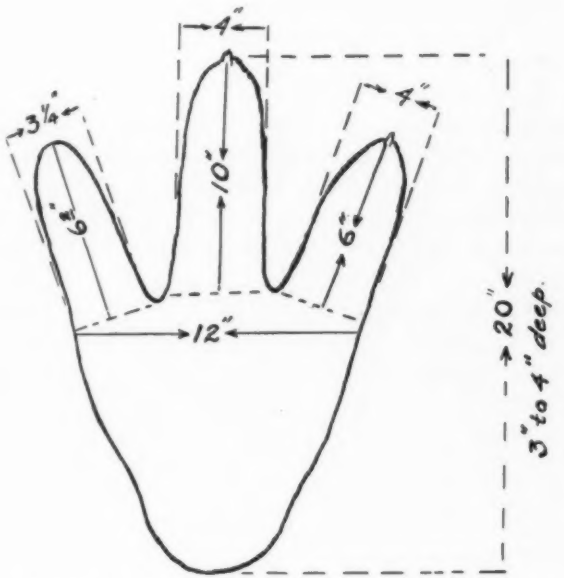



FIG. 5.—Diagram showing dimensions of track in Figure 4

It is interesting to note that R. T. Hill in 1886 found dinosaur bones in the upper strata of the Basement sands of the Lower Cretaceous near Lambert, Parker County,[1] and that he assigned the name "Dinosaur sands" to this horizon.[2] It is reasonably certain that the beds in which the bones were found are approximately the equivalent of those in which the tracks occur in Somervell and Hamilton counties.

The writer expresses no opinion as to whether the tracks in the two localities were made by dinosaurs of the same species. The

[1] *Twenty-first Ann. Rept. U.S. Geol. Surv.*, Part VII, p. 192.

[2] *Amer. Jour. Sci.*, third series, Vol. XXXIII (April, 1887), p. 298.

general shape of the tracks seems to be slightly different. After examining one of the Somervell County tracks, now in the museum of Southern Methodist University at Dallas, it is noticeable that the heel prints shown in Figures 3 and 4 are proportionately longer, narrower, and usually much better developed than in the Glen Rose tracks. The shape of the heel is shown quite clearly in Figure 4. This difference may be due to the fact that the animal, when walking, did not press down heavily on the heel, but carried the weight thrown forward on the toes. The Glen Rose tracks were quite certainly made by an animal in motion, while those in Hamilton County, with the better development of the heel, may have been made in more of a resting position. It would be interesting to make a comparison of a number of the Hamilton County tracks to see whether this difference is characteristic of all the tracks found there.

Dinosaur tracks, exclusive of those found in the Texas Cretaceous, have usually been preserved in sandstone which clearly indicates littoral deposition. The tracks were evidently made by animals walking along a wet, sandy beach or in very shallow water. Shuler adequately discussed this problem in the paper referred to above, and the writer concurs in the conclusions there set forth. The tracks seem to have been made in a soft or plastic ooze which was probably covered by several feet of water. This "lime mud" was probably deposited in broad, shallow, quiet seas, relatively free from currents. There is no noticeable amount of sand in the immediately associated strata. Blue-clay shales carrying selenite crystals occur for at least fifteen feet above and three or four feet below the limestone, and in the overlying shales are thin lenses of coquina bearing a typical Glen Rose fauna.

Mr. C. B. James, of Hamilton, who called the writer's attention to the locality, sent a brief description of the Hamilton County tracks, accompanied by photographs, to the Smithsonian Institution, and in a reply C. W. Gilmore wrote:

> These are in all probability the footprints of one of the large three-toed dinosaurs. Similar footprints have been reported to the authorities of the Institution from near Glen Rose, Texas. The fossil remains of an animal known as Trachodon, have been found in Cretaceous rocks of Texas, which are of sufficient size to have made such tracks as those depicted.

# PROBLEMS IN STRATIGRAPHY ALONG THE ROCKY MOUNTAIN TRENCH

FRANCIS PARKER SHEPARD
University of Chicago

In an investigation of the structure of the Rocky Mountain trench, from Gateway, Montana, to Golden, British Columbia,[1] the writer came in contact with some of the stratigraphic problems of the Canadian Cordillera. For determination of fossils and for helpful criticism he wishes to acknowledge his indebtedness to Dr. Stuart Weller.

## STRATIGRAPHIC SERIES ALONG THE ROCKY MOUNTAIN TRENCH

From the fossils collected at various localities and the sections which have been previously made of the trench, it was possible to map with some degree of accuracy a large part of the zones flanking this great valley (Fig. 1). There are two principal series of rocks represented. One of these is dominantly clastic, the other dominantly limestone. The former contains many metamorphic varieties of shales, sandstones, and conglomerates, but the metamorphism is not extreme. Limestone is not lacking in the clastic series, but most of it is in thin bands. (For convenience this series will be termed the "clastic series.")

The age of these formations is somewhat problematic. In those places where it has been studied hitherto, it has been generally considered pre-Cambrian, but fossils found recently in one locality have shown part of it at least to be as young as Lower Cambrian.[2] That the series is older than Upper Cambrian is indicated by the following points: (1) In a number of places it was found underlying Upper Cambrian formations, and nowhere has it been observed overlying formations containing Paleozoic fossils. (2) It is in general metamorphosed more than formations of the limestone series.

[1] F. P. Shepard, *Jour. Geol.*, Vol. XXX (1922), p. 130.

[2] S. J. Schofield, *Science*, Vol. LIV (1921), p. 666.

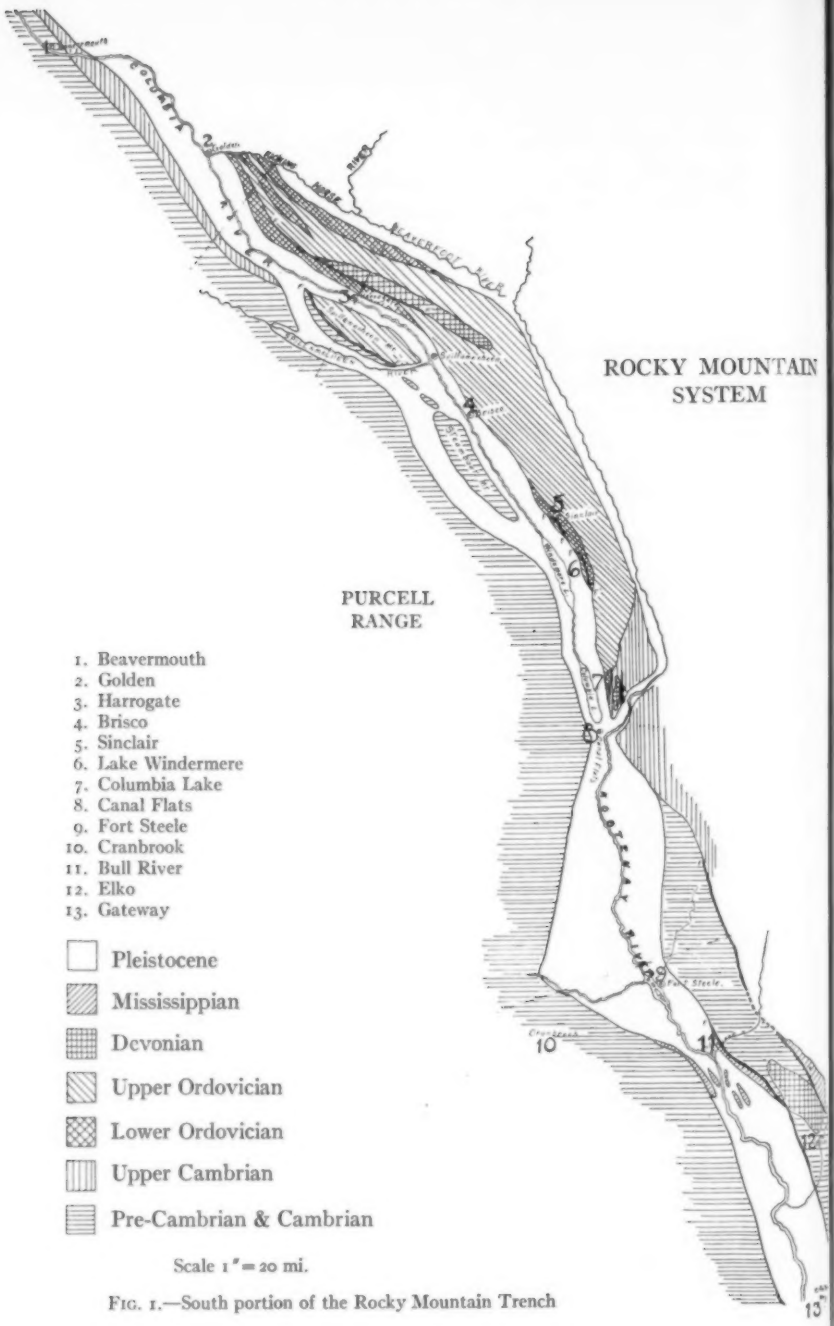



FIG. 1.—South portion of the Rocky Mountain Trench

(3) Fossils were found only in one place, while in the other series they were abundant. No attempt has been made to divide or correlate the different members of the clastic series, because of the great difficulty and the extremely detailed work necessary for classification of unfossiliferous formations in a folded region. A part of it is probably pre-Cambrian.

In the limestone series fossils of the following ages have been found: Upper Cambrian, Lower Ordovician, lower Richmond, upper Richmond, Upper Devonian, and Mississippian. Also the Middle Cambrian horizon at Elko might be considered as part of the "limestone series." Other horizons, including portions of the Silurian, are possibly present. Disconformities are common, showing that there was considerable oscillation of the areas of active deposition. Angular unconformities have not been found but may occur.

Stratigraphic sections were made at several localities along the trench and some of the more representative have been combined into a generalized section (Fig. 2). This section consists chiefly of formations found in the vicinity of Sinclair Springs.

*Upper Cambrian and Lower Ordovician.*—No stratigraphic break has been observed between the Cambrian and Ordovician in the northern portion of the trench visited. Fossils were collected which have been identified by Dr. Walcott as belonging at the top of the Upper Cambrian, and above this is a horizon containing a fauna identified by Dr. Raymond as corresponding to the base of the Ordovician in Europe.[1] Walcott identified the following species:

Dicellomus sp.
Agnostus sp.
Agnostus sp.
Crepicephalus? fragments of cephalon
Ptychaspis cf. striata Whitfield

The species identified by Dr. Raymond included:

Lingulella moosensis
L. allani
Obolus molisonensis
Eorthis desmopleura
E. sp. (ind.)
Cyphaspis brevimarginata
Hemigyraspis mcconnelli
H. carbonensis
Megalaspis shepardi sp. nov.
Dalmanella hamburgensis

[1] P. E. Raymond, *Am. Jour. Sci.*, fifth series, Vol. III, p. 204.

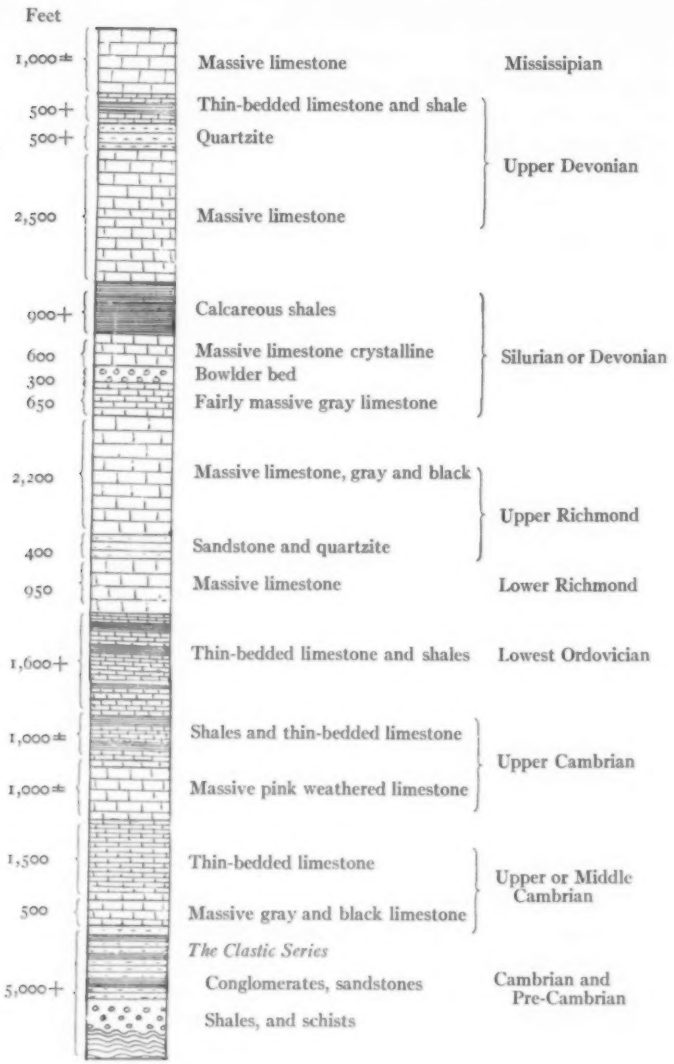



FIG. 2.—Generalized section along the Rocky Mountain trench

| | |
|---|---|
| Syntrophia nundina | Symphysurus cleorus |
| Raphistoma nasoni | S. elongatus |
| Arthrorachis sp. ind. | Menocephalus sp. ind. |
| Hystricurus tuberculatus | |

According to Raymond this is a typical Ceratopyge fauna, comparable to that at the base of the Ordovician in Europe. It has been found in several other localities in the west directly overlying the Upper Cambrian, and Dr. Raymond thinks that it implies the absence of the Ozarkian series from the west.

*Upper Ordovician and Silurian.*—Comparing the section made by Allen[1] along the main line of the Canadian Pacific with that of the trench, there are seen to be some resemblances but several important differences.

SECTION ALONG THE CANADIAN PACIFIC

(After Allen)

| System | Formation | Thickness | |
|---|---|---|---|
| | | Feet | Meters |
| Mississippian | Lower Banff shale | 1,200 | 366 |
| | Lower Banff limestone (partly Devonian) | 1,500 | 457 |
| Devonian | Intermediate limestone | 1,800 | 548 |
| | Sawback limestone (Devonian?) (thickness, 1,128 m.) | ..... | ..... |
| Silurian | Halysites beds | 1,850 | 563 |
| Ordovician | Graptolite shale | 1,700 | 518 |
| | Goodsir shale | 6,040 | 1,841 |
| Upper Cambrian | Ottertail limestone | 1,725 | 526 |
| | Chancellor shales | 4,500 | 1,372 |
| | Sherbrooke limestones | 1,375 | 419 |
| | Paget limestones | 360 | 110 |
| | Bosworth limestones | 1,855 | 565 |
| Middle Cambrian | Eldon limestones | 2,728 | 831 |
| | Stephen limestone-shale | 640 | 196 |
| | Cathedral limestones | 1,595 | 486 |
| Lower Cambrian | Mt. Whyte sandstone shale | Rocky Mountains | |
| | St. Piran quartzite | | |
| | Lake Louise shale and sandstone | ..... | ..... |

[1] J. A. Allen, *Can. Geol. Surv. Guidebook No. 8*, Part 2, p. 120.

In Allen's section the Halysites limestone is placed in the Silurian. This formation, however, contains the same fauna that is found in the formation considered upper Richmond in the accompanying section (Fig. 2). The fauna contains the corals which are generally typical of the Silurian, namely Halysites catentulatus, Favosites, but these are also known to occur in the west in formations which are generally considered to be Ordovician,[1] as for example in the upper portion of the Big Horn limestone. The fauna also includes characteristic Upper Ordovician (Richmond) brachipods among which a form of Rhynchotrema capax is most common. Whether Silurian strata are actually present in the section is open to question. In two localities, overlying the upper Richmond and underlying formations of Devonian age, there are several thousand feet of limestone and shale in which no fossils were found. In one locality the upper Richmond is overlain by a bowlder bed which strongly suggests tillite,[2] and as Silurian tillites have been reported in southeastern Alaska[3] at a similar horizon, it is possible that this formation is of the same age.

*Devonian.*—The Devonian seas probably invaded the Rocky Mountain trench from two directions. An invasion from the south by an arm of the Jefferson seas, which covered most of the Rocky Mountain region of the United States, is believed to have occupied the southern portion of the trench. Formations of this age have been found by Daly at the international boundary line[4] and again farther north near Elko and Canal Flats by Schofield.[5] The fossil species collected from this formation, which are also known to be present in the Jefferson limestone are Spirifer englemani and S. utahensis, both of which are guide fossils for the Jefferson.

Highly fossiliferous Devonian strata were also observed a mile east of Harrogate in the Beaverfoot Range. The fauna is unlike that of the Jefferson limestone, but is related to that of the Devonian formations off the MacKenzie River district to the north,

[1] N. H. Darton, *Bull. Geol. Soc. of Am.*, Vol. XV, p. 399.

[2] F. P. Shepard, *Jour. Geol.*, Vol. XXX (1922), p. 89.

[3] E. Kirk, *Am. Jour. Sci.*, fourth sec. (September, 1918), p. 511.

[4] R. A. Daly, *Geol. Surv. Can. Mem. 38*, p. 115.

[5] S. J. Schofield, *Geol. Surv. Can. Mem. 76*, p. 53.

an occurrence which suggests the extension of an arm of the MacKenzie Devonian sea into the northern part of the trench. The fossil forms in this fauna which are also known in the MacKenzie Devonian include the following species:

| | |
|---|---|
| Martinia meristoides | Spirifer tulia |
| Reticularia fimbriata | Atrypa reticularis |
| Schizophoria macfarlini | Astraespongia hamiltonensis |
| S. striatula | Heliophyllum halli |

a faunal group which suggests late Middle or early Upper Devonian age.

Whether this invasion from the MacKenzie basin was contemporaneous with that from the south, with the two submergences separated by a land barrier in the Lake Windermere district, is not established, but the invasion from the north was probably somewhat later than that from the south.

*Mississippian.*—The Mississippian is known to occur only in the southern portion of the trench in the vicinity of Wardner and Bull River, where it was discovered by Schofield.[1] Dr. Raymond identified the following species:

| | |
|---|---|
| Camarophoria explanata | Cleiothyridna crassicardonalis |
| Camaroechia cf. C. metallica | Spirifer cf. S. centronatus |
| Composita madisonensis | Productella cooperensis |

## RELATION OF PRE-CAMBRIAN TO CAMBRIAN

The stratigraphic relation of the Cambrian sediments to the pre-Cambrian formations in the Canadian Cordillera has been the subject of considerable discussion. Daly considers the two series to be essentially conformable, while Walcott and Schofield think them unconformable.

The situation along the main line of the Canadian Pacific is well summed up by Daly in his report of the "Reconnaissance between Kamloops and Golden."[2] The thick lower Cambrian fossil-bearing members have at their base a conglomerate (the Fairview formation). Below this the Hector Shale is considered

[1] S. J. Schofield, *Geol. Surv. Can. Mem. 76*, p. 57.

[2] R. A. Daly, *Geol. Surv. Can. Mem. 68*, pp. 87–93.

to be pre-Cambrian. Walcott[1] believes that between these two formations there is an unconformity, shown by the following: (1) The overlying conglomerates contain fragments of the Hector shale. (2) Slight hollows in the Hector shale are filled with thin sandstone lenses. (3) The underlying Beltian (Proterozoic) formation varies in character at the contact from place to place. (4) The sediments seem to change from brackish water in the Beltian, to marine in the Cambrian. (5) Allen's discoveries of the contact between the Hector shale and the Fairview formation showed apparent conformity in one place, while in two others discordance of dip of 4°.

Daly makes the following reply to these arguments: (1) The fragments of the Hector shale in the overlying Fairview conglomerate are all angular and do not show a significant time break. (2) The Fairview is nearly identical with formations occurring at various horizons in the pre-Cambrian. (3) The sandstone beds in the upper surface of the Hector are merely lenses which are common elsewhere in the Beltian. (4) The discordance of dip seen between the Hector and the Fairview can be explained by irregularities in uplift as such are seen in continuous sedimentary series in many localities. (5) The Selkirk series is divided on lithological grounds into Cambrian and pre-Cambrian with the dividing plane in the Ross quartzite, where there is no sign of unconformity.

Daly's first four points appear to be sound. Walcott's arguments for an unconformity lack proof that a time break is represented. There might well have been a change in the conditions of sedimentation without unconformity. In the natural order of clastic sedimentation it is to be expected that there will be some stirring of older sediments by changes in the activity of the currents. In the "clastic series" along the west side of the trench many examples of such disturbances are found. It seems that more evidence is necessary here to warrant the conclusion of an unconformity of importance between the two systems. Minor disconformities are of course present in great numbers in most thick sedimentary series, especially if there are clastic sediments.

[1] C. D. Walcott, *Smithsonian Misc. Coll.*, Vol. LVII, p. 343.

In regard to Daly's fifth point concerning the Selkirk series, recent evidence shows that the age of the series is very uncertain.[1] As stated above, Daly places the dividing line between the Cambrian and the pre-Cambrian in the Ross quartzite, because of lithological resemblances of the sequence of formations in the Canadian Rockies and the Selkirks, but the discovery of upper Paleozoic fossils in the Laurie formation, which underlies the Ross quartzite formation by 12,650 feet and is separated from it by the Nakimu limestone and the Cougar quartzite, disproves this conclusion.

A recent observation further complicates the situation.[2] The Cougar quartzite was found underlying the Upper Cambrian

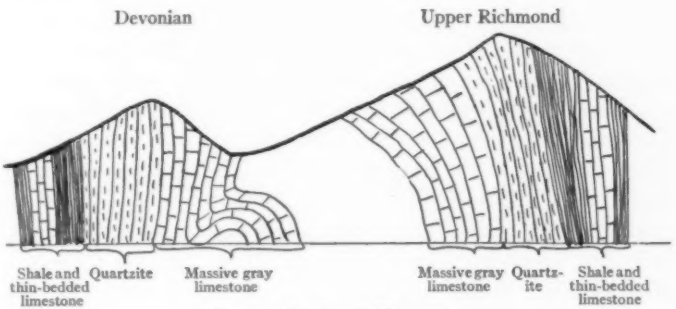



FIG. 3.—Section at Harrogate

shales and limestones on the west side of the trench at Golden, and, while a detailed study of the contact was not made, it appears probable that there was at least no angular unconformity separating the two formations. Therefore one discovery places the Cougar formation above upper Paleozoic fossils and the other places it below the Upper Cambrian. It seems probable that the series in the Purcell Range is not of the same age as that in the Selkirks, a conclusion which seems more likely when it is considered that the section in the Purcell Range exhibits only a part of two of the formations which are present also in the Selkirks (Fig. 3).

[1] L. D. Burling, *Bull. Geol. Soc. Am.*, Vol. XXIX, p. 146.

[2] F. P. Shepard, *Jour. Geol.*, Vol. XXX (1922), p. 146.

In the southern part of the trench Daly and Schofield are not in agreement as to the dividing line between the Cambrian and the pre-Cambrian. In Daly's "Forty-ninth Parallel Survey" the division between the Cambrian and the Beltian was placed within the "clastic series" between the Altyn formation below and the Hefty formation above.[1] This report was based on reconnaissance work in the field, and the division of the unfossiliferous formations was necessarily quite arbitrary. Schofield's more detailed work in the Cranbrook area[2] made changes in Daly's classification and produced more evidence concerning the age of the unfossiliferous series. He found Middle Cambrian fossils in the Burton formation near Elko, and below this, while there are no angular unconformities, there are marked signs of disconformity. There is a thin basal conglomerate at the base of the Middle Cambrian, and the surface of the Roosville formation beneath is somewhat weathered. From these facts Schofield concluded that there is an unconformity at the top of the Lower Cambrian, and placed the Roosville in the pre-Cambrian. Since the Roosville is the highest member of the "clastic series" (which is represented), this places all of that series in the pre-Cambrian. Recently, however, Colonel Pollin discovered a remarkably fine trilobite fauna in a formation which is probably lower than the Roosville. According to Walcott the fossils indicate a horizon at the top of the Lower Cambrian. Therefore the extent of the disconformity near Elko is minimized, and incidently Daly's original dividing line between the Cambrian and the Beltian is more nearly correct than that of Schofield.

However, Schofield has again attempted to find an unconformable relation between the Cambrian and the pre-Cambrian.[3] His evidence for this includes: (1) The thickness of sediments of the Siyeh formation between the Purcell lava and the basal conglomerate of the Lower Cambrian, varies from a few feet to 300 feet. (2) The lithological and metamorphic contrast above and

[1] R. A. Daly, *Geol. Surv. Can. Mem. 38*, p. 179.

[2] S. J. Schofield, *Geol. Surv. Can. Mem. 76*, pp. 41–52.

[3] S. J. Schofield, *Science*, Vol. LIV, p. 666.

below is marked. (3) Basal conglomerates of the Cambrian have rounded fragments of the underlying argillites.

This evidence does not necessarily place the underlying Siyeh formation in the pre-Cambrian. That the Olenellus horizon is not nearly at the base of the Cambrian is shown by the great thickness of Lower Cambrian below the Olenellus horizon in the Waucobian of California. Whether the length of the time bridged in this disconformity is sufficient to place the underlying formations in the Beltian, is open to doubt for the following reasons: (1) The degree of metamorphism varies greatly in members of the same age in the Purcell series. (2) The difference in the thickness of the Siyeh formation is not important, because of its clastic nature. (3) The occurrence of the conglomerate does not prove an unconformity, as conglomerates are common in the "clastic series." (4) Since there are great abundance and all varieties of argillites in the "clastic series" the fragments of argillites in the Cambrian conglomerates may have come from argillites other than those directly underlying the conglomerate. In general it may be said that minor unconformities are to be expected in a series of this sort, and their significance is not great. Since the contact of the Cambrian on the pre-Cambrian has been especially well studied, it is not surprising that minor unconformities should be found at some horizon not far below the lowest horizon that is known to be fossiliferous.

From observations on the relation of the "clastic series" to the "limestone series" farther north in the trench, new but rather incomplete evidence was found of the relation between the older series and the Upper Cambrian limestones (the base of these limestones may be Middle Cambrian). At Premier Lake, below what are probably the Upper Cambrian limestones, there is a series of argillaceous quartzites and shales. While no accurate measurement of the series was made, it was estimaetd to be at least 5,000 feet thick. As the series was examined in several places and was found to be quite similar in character in all of them, the condition of sedimentation is thought not to have varied in any important degree. This series is probably, at least in part, of the same age as the Purcell and Galton series farther south. The Purcell series

is only 15 miles to the south in the Fort Steele region, and appears to be traceable this far north. The clastic nature of the deposits as against the limey deposits of the Upper Cambrian (and perhaps Middle Cambrian) indicates that there was variation in the character of the sedimentation in the Cambrian. In the vicinity of Parsons the Upper Cambrian is somewhat argillaceous, but the base of the Ordivician is mostly limestone.

If the Beltian is actually present at the base of the "clastic series," it seems as though the greatest change during the Beltian and Cambrian times was a change from semiterrestrial and near shore deposits to deposits in clear broad seas. Probably this change is of more importance than any minor unconformities that may exist below the lowest rocks which are known to contain fossils.

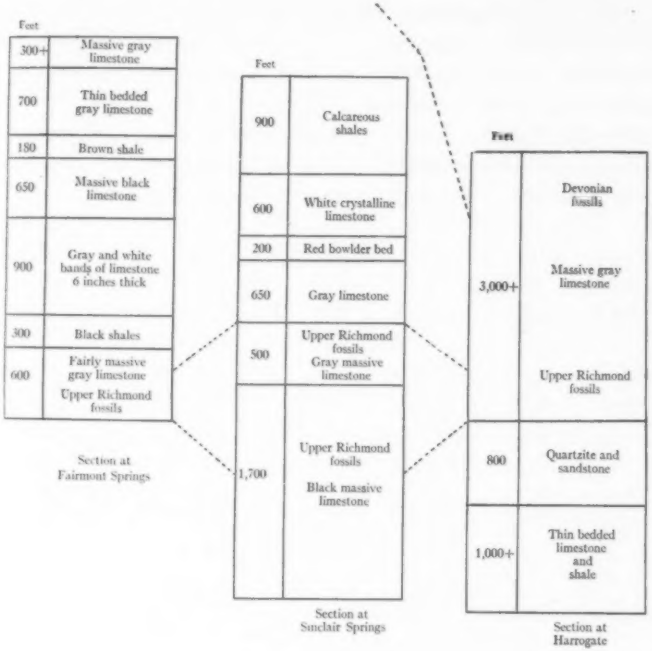
### CORRELATION OF UNFOSSILIFEROUS FORMATIONS

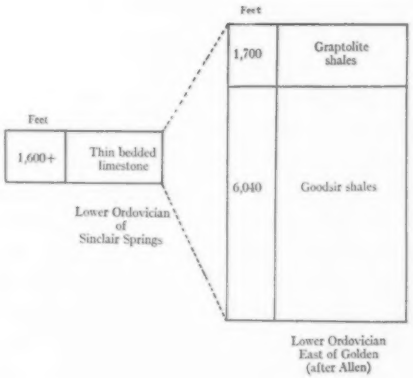
Correlation of the unfossiliferous formations over wide areas by lithological comparison has been resorted to frequently in the Cordillera. Dawson, McConnell, and others who made the pioneer surveys of the region relied especially on this method. Daly, as has been shown above, also correlated formations of widely separated portions on the same basis. Mistakes made in one of these attempts is illustrated by the recent findings concerning the Purcell series (p. 369).

The most detailed work on the unfossiliferous formations is that by Schofield in the Cranbrook area. Here the members of the Purcell series are mapped over an area of about 2,500 square miles. The characteristics of the different formations are such that they are likely to vary considerably, and to grade from one into another rather readily, so that with the great complication of the fault system in the region, a classification is extremely difficult.

From observations based chiefly on the fossiliferous formations, it appears that classification of the unfossiliferous formations is especially complicated by the extreme variability of the lithology, and of the metamorphic character of the formations along the trench.

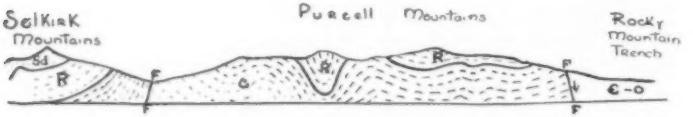
*Lithological variations.*—The lithological character of the different horizons in the Paleozoic was examined at several places along


Feet
300+
Massive gray limestone
700
Thin bedded gray limestone
180
Brown shale
650
Massive black limestone
900
Gray and white bands of limestone 6 inches thick
300
Black shales
600
Fairly massive gray limestone
Upper Richmond fossils
Section at Fairmont Springs
Feet
900
Calcareous shales
600
White crystalline limestone
200
Red bowlder bed
650
Gray limestone
500
Upper Richmond fossils
Gray massive limestone
1,700
Upper Richmond fossils
Black massive limestone
Section at Sinclair Springs
Feet
3,000+
Devonian fossils
Massive gray limestone
Upper Richmond fossils
800
Quartzite and sandstone
1,000+
Thin bedded limestone and shale
Section at Harrogate


Feet
1,600+
Thin bedded limestone
Lower Ordovician of Sinclair Springs
Feet
1,700
Graptolite shales
6,040
Goodsir shales
Lower Ordovician East of Golden (after Allen)

the east side of the trench. The change in the character of the beds containing the same faunal succession was the more notable because the formations were dominantly calcareous. A few sample sections (p. 373) will illustrate this point.

The lithology of a section east of Harrogate (Fig. 4) would indicate that there is an anticline or syncline forming the summit of the Beaverfoot Range, because of the apparent repetition of




Є-O = Ordovician and Upper Cambrian
Sd = Sir Donald quartzite (Lower Cambrian)
R = Ross quartzite (Lower Cambrian and Beltian)
C = Cougar quartzite (Beltian)

Section along the main line of the Canadian Pacific Railway (after Daly)

Є-O = Ordovician and Upper Cambrian
R = Ross Quartzite (Upper Cambrian?)
C = Cougar Quartzite (Cambrian?)

Same section revised

FIG. 4

the same formations in reverse order on the two sides. However, fossils proved that this reversed succession was a mere coincidence, and, as shown in the section, one side of the supposed anticline is Devonian and the other Ordovician. An occurrence of something of this sort in the Cranbrook area, or wherever else fossils were lacking, could very easily introduce error into the classification.

*Metamorphic variations.*—Metamorphic variations are especially important in the Purcell Range on the west side of the trench. This is perhaps especially true in the Cranbrook area, where there are more igneous intrusions than farther north, but

even where the intrusions are absent metamorphism is found to vary greatly. In the Selkirk Range along the main line of the Canadian Pacific Railway, where there are no intrusives, the upper Paleozoic Laurie formation contains the same type of semi-metamorphic beds as are found farther east in the lower portions of the Cambrian. Many of the upper Paleozoic rocks of the Arrow Lake region are more metamorphosed than the pre-Cambrian (or early Cambrian) beds to the east in the Cranbrook area. This last case is probably explained by contact metamorphism.

A quartz grit having well-rounded quartz pebbles and a calcareous cement was found in several places along the west side of the trench in the vicinity of Lake Windermere. This formation was associated with argillaceous rocks which varied from shales to schists in the different localities, although it most likely represents the same horizon because of its very distinctive characteristics, which were not found in any other formation.

At Sinclair Springs there is a bed of highly crystalline limestone which is higher in the stratigraphic series than another limestone which is not crystalline. So many similar cases were found that it seems as though the anamorphic influences along the trench were very irregular. The cause of this irregularity is varied. In the southern Purcells, the intrusions are chiefly responsible. Farther north the intrusives rarely appear at the surface, but their presence below the surface is shown by the hydrothermal alteration of the rocks in many places along the west side of the trench. In the northern portion, however, the most important anamorphic results are connected with diastrophic movements. In the vicinity of large faults the alteration is often more pronounced than elsewhere. The Purcell Range was probably deformed at two periods[1] so that the formations on that side would tend to be differently metamorphosed from those of corresponding age on the other side. At present the exposed pre-Cambrian and later formations are found at the same general level, but formerly the pre-Cambrian was more deeply buried. As deformation went on, the pre-Cambrian was brought gradually toward the level of the younger formations by folding and faulting. After the two reached

[1] S. J. Schofield, *Geol. Surv. Can. Mem. 76*, p. 101.

the same level, metamorphism would tend to be somewhat equal in effects on each. Before that time the more deeply buried pre-Cambrian would tend to be more severely metamorphosed unless it was below the zone in which the most effective compression was being concentrated. Further confusion in regard to differential metamorphism may be produced by the cutting of great valleys in the rising mountain ranges. Along the lines of these valleys the overburden is less, and therefore there would be less severe metamorphism. Thus the amount of metamorphism of a local series of rocks in this general region can only be used to tell its relative age in exceptional cases.

The foregoing consideration of the varying character of the lithology and metamorphism is intended to show how extremely difficult it is to correlate unfossiliferous formations in a mountainous region. Attempts at such correlations are of course suggestive, but they should be duly qualified.

# A SCALE OF GRADE AND CLASS TERMS FOR CLASTIC SEDIMENTS[1]

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## INTRODUCTION

In no other science does the problem of terminology present so many difficulties as in geology. With the growth of knowledge in any field of investigation, men devise new terms or redefine old ones in the attempt to convey more precise and definite ideas. In all the branches of science much confusion has followed the redefinition of old terms because of the indiscriminate use of the terms both in the old and the new senses. But in geology, difficulties of this kind are peculiarly great.

Because geology is a field science and has followed in the footsteps of exploration, it has acquired terms from all parts of the world. Many of the names for the less common special features have come from the dialect or colloquial speech of that part of the world where they are best developed. With the use of these terms of geologists of other regions, much irregularity of usage and hence much confusion has arisen.

Since 1917, the writer had been engaged in the study of abrasion and shaping of cobbles and pebbles by the action of running water. In the course of this study the loose usage of cobble, pebble, and related terms (in which his own practice was no exception) has impressed him with the need of greater uniformity of usage and

[1] Published by permission of the Director of the United States Geological Survey.

more careful definition of such terms. With this need in mind, he sent to about sixty of his colleagues of the United States Geological Survey a questionnaire asking them to give the limiting dimensions in their conception or usage of the terms bowlder, cobble, pebble, sand grain, and clay particle. Replies were received from about thirty of the men. These were studied and compared and the composite results presented in preliminary unpublished form which was distributed to more than one hundred geologists throughout the country in the hope of receiving additional comment and criticism. A small number of very helpful replies were received and utilized in modifying, to some extent, the size limits and the terms used.

Early in 1921, mimeographed copies of this modified scheme of terms were sent to about a dozen geologists in this country and England who were known as workers in the field of sediments and sedimentary rocks, and deemed competent to criticize the usages proposed. They were asked to reply to specific questions in regard to the terms which had been subject to the most criticism and to comment in general upon the plan. The replies from this smaller group were most gratifying, since nearly every geologist addressed sent a reply which the writer found useful in the preparation of the classification here presented.

In addition to the studies mentioned above, the writer commenced in 1920 the collection of definitions of sedimentary rock terms. These definitions are taken verbatim from textbooks, dictionaries, encyclopedias, and glossaries. They are typewritten on cards with the proper references and filed under the name of the term defined. Many of the definitions collected are from sources seventy-five to one hundred years old and represent the former usage of certain terms as understood by the compiler. The definitions collected in this way vary greatly in value and none is to be regarded as of absolute authority. They constitute, however, part of the data of the problem.

As will appear from the foregoing, the writer has compiled the present scheme of classification in part from a specific study of the terms here presented and in part from the results of a general consideration of terms in the field of sedimentary rocks. He is

indebted to a large number of geologists who have helped him by spoken and written criticism. Space will permit acknowledgment of gratitude only to Dr. M. I. Goldman and to Dr. J. B. Woodworth, whose interest and frank criticism have been especially helpful in the preparation of this paper.

## THE GRADE TERMS

It is the writer's purpose here to suggest terms which are specific as regards size of piece and, at least for the larger pieces, as regards shape of piece. The terms of this scheme apply to rounded materials in so far as materials of the size in question become rounded by transportation. Strict uniformity in this regard will not fit the sediments as they occur in nature. Bowlders, cobbles, and pebbles are rounded rock fragments, whereas most clay particles are angular, yet geologists will recognize that they all belong to a natural series. Likewise, bowlders and clay particles are not commonly of the same mineral composition but in spite of this fact they are the two extremes of the series of transported rock fragments. By an excessive multiplication of terms it would be possible to make a classification in which each term was specific as to size of particle, shape of particle, lithologic character, and other characteristics. Such a scheme would be highly artificial in many of its categories and seems to the writer impracticable in the present state of knowledge.

The present scheme of grade terms is, accordingly, just what its name implies—a series of names for clastic fragments of different sizes. They apply only to rounded fragments except in the case of fine sands, silts, and clays in which even prolonged transportation does not always round the pieces. The names applied to the different grades carry no lithologic, mineralogic, or chemical significance so far as the present scheme is concerned. Sands are dominantly quartzose, whereas clays are largely made up of kaolin, but this fact is incidental and not necessary in the use of the terms.

## FRAGMENT TERMS

*Bowlder.*—This term is in common use in English-speaking countries for rounded and smoothed masses of rock larger than

cobbles[1] resulting from abrasion in transportation. Angular masses of rock of the same size are commonly called blocks or slabs. The word bowlder is related to the English word *bellow*; compare Swedish *bullra*, to *rattle* or *roar*. Equivalent terms in several other languages carry similar ideas of rumbling or rolling in their derivation.

*Cobble.*—Cobble or cobblestone is used generally, both by geologists, and in common speech, for a rounded stone smaller than a bowlder and larger than a pebble. The term is a diminutive of the word *cob*, meaning a rounded hump or knob, and related to the German *Kopf*, for head.

*Pebble.*—This term is a very ancient one which is used commonly for rounded, transported rock fragments smaller than cobbles. In the past it was more commonly used than it is at present for rounded stones up to the size of bowlders. The tendency now is to use the term cobble in an intermediate sense, as stated above. Pebble is from the Anglo-Saxon *papol*, which meant something small and round, perhaps akin to the Latin *papula*, a *pustule*.

*Granule.*[2]—The term granule is here proposed by the writer as a term for rounded rock fragments larger than very coarse sand grains but smaller than pebbles. Rounded pieces too small to be called pebbles have still been too large to be called sand grains in the practice of most geologists. Granule is from the Latin *granulum*, diminutive of granum, *grain*, meaning a *little grain*, a *pellet*. In spite of apparent infelicity of meaning (little grain), this term was chosen as best adapted for this grade of material. The term grit grain was considered for use in this sense, but was thought less satisfactory. Grit is used in another sense, as for fine sandstone of angular grain. It seemed undesirable to include these grains either with small pebbles or with coarse sand grains, and it is hoped that the term granule may fill an apparent gap in the series of terms heretofore used.

*Sand grain.*—The several terms made up by the use of adjectives qualifying sand grain are self-explanatory.

[1] For explanation of the basis on which the sizes limiting the several grades were chosen, see the text which follows.

[2] This term was suggested to the writer by Dr. Herbert A. Baker, of England.

*Silt particle.*—The term silt particle is here applied to individual particles smaller than very fine sand grains but larger than clay particles. The term silt from which it was derived was objected to by some geologists on grounds that are stated under the heading of silt. These grounds were not sustained even by a minor part of the data available to the writer and the term is here used as the most satisfactory one.

TABLE I

THE GRADE TERMS

| The Pieces | The Aggregate | The Indurated Rock |
|---|---|---|
| Bowlder | Bowlder gravel | Bowlder conglomerate |
| 256 mm. | | |
| Cobble | Cobble gravel | Cobble conglomerate |
| 64 mm. | | |
| Pebble | Pebble gravel | Pebble conglomerate |
| 4 mm. | | |
| Granule | Granule gravel | Granule conglomerate |
| 2 mm. | | |
| Very coarse sand grain | Very coarse sand | Very coarse sandstone |
| 1 mm. | | |
| Coarse sand grain | Coarse sand | Coarse sandstone |
| 1/2 mm. | | |
| Medium sand grain | Medium sand | Medium sandstone |
| 1/4 mm. | | |
| Fine sand grain | Fine sand | Fine sandstone |
| 1/8 mm. | | |
| Very fine sand grain | Very fine sand | Very fine sandstone |
| 1/16 mm. | | |
| Silt particle | Silt | Siltstone |
| 1/256 mm. | | |
| Clay particle | Clay | Claystone |

*Clay particle.*—After consideration of several other terms for the materials finer than silt, the term clay was finally adopted as most likely to meet with general approval. Clay particle is therefore used for the individual pieces.

*The size limits.*—In fixing the limiting sizes of the several grades of the scheme shown in the table, the writer has been governed by two considerations. First, there is a growing acceptance among geologists and engineers of a series of sieves for the classification of natural clastic materials in which the openings of consecutive size stand to one another in the ratio 2 or $1/\sqrt{2}$ starting with 1 mm. as the standard.

It has long been recognized that the differences between two consecutive screen size openings should be greater for the large sizes than for the small. This principle is followed in the selection of such limits as 1, 2, 5, 10, 20 millimeters, making the limits fall on convenient whole numbers in the decimal notation. This series, however, is a crude approach to a geometrical series in which each value bears a constant ratio to the preceding one. A geometrical series is the ideal for such a purpose, since a change of 1″ is of the same significance and importance in the size of 10″ cobbles as a change of $\frac{1}{10}$″ in the size of 1″ pebbles. Only by the use of logarithmic or some similar graphical scheme of representation can the size composition data be shown adequately for great size ranges. The use of a geometrical series makes the successive grades fall into equal units on the graph—an arrangement much easier to read and interpret than any other known to the writer. The most convenient ratio for the construction of such a series is the ratio 2, and the most convenient and logical starting-point, 1 mm. A large number of mechanical analyses of sediments made with screens and by microscopic measurement conforming to such a series have been made.[1] If a more minute subdivision is needed, the ratio $1:\sqrt{2}$ can be used, giving twice the number of grades, or in exceptional cases $1:\sqrt[4]{2}$. These extra subdivisions fit in with and form further subdivisions of the fundamental series of the powers of 2. Conformity to this geometrical series is the first consideration which has guided the writer in fixing the limits between the several grade terms.

The second consideration has been the desire to make each of the limits as close as possible to the common practice of the majority of geologists. Figure 1 shows the composite opinions of twenty-eight geologists of the United States Geological Survey, as reported by them in response to a questionnaire on the sizes limiting several of the terms. The table below shows a number of different schemes of classification which have been published. There is a close agreement between some of those shown, but, with the exception of that of Udden, all lack, in the sizes of successive grades, the uniformity

[1] J. A. Udden, "Mechanical Composition of Clastic Sediments," *Bull. Geol. Soc. Amer.*, Vol. XXV (1914), pp. 655–744.

of ratio of the geometrical series which seems to the writer to be essential to any thorough quantitative study of the mechanical composition of sediments.

Using the data shown in Figure 1 and Table II, the writer has selected the limits conforming to the power series of 2 which most closely conform also to the concensus of the opinions

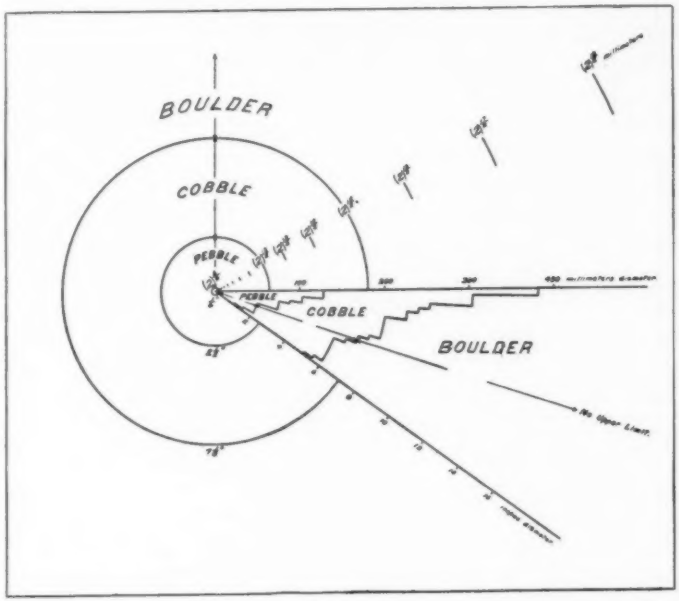


FIG. 1

of authorities quoted there. The names of the several grades thus established were then chosen as described above.

### AGGREGATE TERMS

The assignment of definite limiting size values to the terms for the aggregates as named below, as well as the rocks named in another part of this paper, will be objected to on the ground that aggregates are not made up in nature of one grade or even of a few grades, and that therefore the names are inapplicable. The author

## TABLE II

| New York City* Aqueduct Commission | K. Keilhack† | J. Thoulet‡ | A. W. Grabau§ | Orth‖ | J. S. Diller¶ | United States** Bureau of Soils | H. A. Baker†† | J. A. Udden‡‡ | Classification Here Proposed |
|---|---|---|---|---|---|---|---|---|---|
| | | | Bowlders | | | | | | Bowlder gravel |
| | | | 150 mm. | | | | | 256 mm. | 256 mm. |
| Coarse Gravel | Gravel | | Cobbles | | | | | Large bowlders 128 mm. | Cobble gravel |
| | | | 50 mm. | | | | | Medium bowlders 64 mm. | 64 mm. |
| | | | Very course gravel | | | | | Small bowlders 32 mm. | |
| | | | 25 mm. | Gravel | Gravel | | | Very small bowlders 16 mm. | Pebble gravel |
| | | | Coarse gravel | | | | | Very coarse gravel 8 mm. | |
| 5 mm. | | Fine gravel | 5 mm. | | | | Gravel | Coarse gravel 4 mm. | 4 mm. |
| Fine gravel | 2 mm. | 3 mm. | Fine gravel 2.5 mm. | 3 mm. | 2 mm. | 2 mm. | 2 mm. | Medium gravel 2 mm. | Granule gravel 2 mm. |
| 1 mm. | Very coarse sand | Coarse sand | Very coarse sand | Very coarse sand | Fine gravel | Fine Gravel | Very coarse sand | Fine gravel 1 mm. | Very coarse sand 1 mm. |
| Coarse sand | 1 mm. | .89 mm. | 1 mm. | 1 mm. | 1 mm. | 1 mm. | 1 mm. | Coarse sand 1/2 mm. | Coarse sand 1/2 mm. |
| .5 mm. | Coarse sand | Medium sand | Coarse sand | Coarse sand | Coarse sand | Coarse sand | Coarse sand | Medium sand 1/4 mm. | Medium sand 1/4 mm. |
| Medium sand | .5 mm. | .45 mm. | .5 mm. | .5 mm. | .5 mm. | .5 mm. | .5 mm. | Fine sand 1/8 mm. | Fine sand 1/8 mm. |
| .25 mm. | Medium sand | Fine sand | Medium sand | Medium sand | Medium sand | Medium sand | Medium sand | Very fine sand 1/16 mm. | Very fine sand 1/16 mm. |
| Fine sand | .2 mm. | .26 mm. | .25 mm. | .25 mm. | .25 mm. | .25 mm. | .25 mm. | Coarse silt 1/32 mm. | |
| .1 mm. | Fine sand | Very fine sand | Fine sand | Fine sand | Fine sand | Fine sand | Fine sand | Medium silt 1/64 mm. | Silt |
| Superfine sand | .1 mm. | | .1 mm. | .1 mm. | .1 mm. | .1 mm. | .1 mm. | Fine silt 1/128 mm. | |
| .05 mm. | Superfine sand | .04 mm. | Superfine sand | .05 mm. | Very fine sand | Very fine sand | Coarse silt | Very fine silt 1/256 mm. | 1/256 mm. |
| Rock flour | .05 mm. | Fine-fine sand | .05 mm. | Rock flour | .05 mm. | .05 mm. | .05 mm. | Coarse clay 1/512 mm. | |
| .01 mm. | Dust | | Rock flour | .05 mm. | Silt | Silt | Silt | Medium clay 1/1024 mm. | Clay |
| Superfine rock flour | .01 mm. | | .01 mm. | Dust | .01 mm. | .005 mm. | .01 mm. | Fine clay 1/2048 mm. | |
| .005 mm. | | | Superfine rock flour | .01 mm. | Finest silt | | Clay | | |
| Clay size | Finest dust | | .005 mm. | Finest dust | .005 mm. | Clay | | | |
| | | | Clay size | | Clay | | | | |

* Quoted by A. W. Grabau, *Principles of Stratigraphy* (1913), p. 286.

† Konrad Keilhack, *Lehrbuch der praktischen Geologie* (1908), 2te Auflage, Stuttgart, Ferdinand Enke.

‡ J. Thoulet, *Précis d'analyse de fonds sous-marins actuel et anciens*, p. 64, Paris, R. Chapelot & Cie.

§ A. W. Grabau, *Principles of Stratigraphy* (1913), New York, A. G. Seiler & Company.

‖ Orth, *Bezeichnung des Sandes nach der Grösse des Kornes. Neues Jahrbuch für Mineralogie*, p. 551, Volume for 1875.

¶ J. S. Diller, *U.S. Geol. Surv., Bull. 150* (1902), p. 380.

** United States Bureau of Soils, *Soil Survey Field Book* (1906), pp. 17, 18.

†† H. A. Baker, *On the Investigation of the Mechanical Constitution of Loose Arenaceous Sediments by the Method of Elutriation, with Special Reference to the Thanet Beds of the Southern Side of the London Basin*, p. 2, London, Dulan & Co., 1920.

‡‡ J. A. Udden, "Mechanical Composition of Clastic Sediments," *Bull. Geol. Soc. Amer.*, Vol. XXV (1914), pp. 655–744.

recognizes this difficulty and the grade terms here defined are applicable strictly and without modification to but few natural sediments. They are proposed as the foundation of, and in the course of development of, the several class terms and adjectives proposed in the last part of this paper. Photographs of grade aggregates from 64 mm. to $\frac{1}{32}$ mm. are shown in the accompanying Figures 2 and 3.

*Gravel.*—Among some geologists the term gravel has been used only for material composed of small pebbles and granules, but more commonly and especially in America and in reference to glacial gravels, the term has been used to include material containing great bowlders up to a meter or more in diameter, and has recently been so defined by J. S. Flett[1] who considers the term to be the equivalent of conglomerate as applied to the consolidated rocks. It is in this latter and prevailing sense that the term is here used and combined with qualifying words in the terms bowlder gravel, cobble gravel, pebble gravel, and granule gravel.

*Sand.*—The term sand is in common use among all English-speaking geologists for mineral grains smaller than 1 or 2 mm. and larger than silt. By some writers, sand is applied only to rounded mineral grains, but others use the term more generally. Sand is from the Anglo-Saxon word of the same spelling and meaning.

*Silt.*—The term silt is considered by some geologists to apply properly to deposits containing organic matter in addition to the mineral particles. The writer was unable to find any considerable support of this view by either past or present authorities, and has here used the term for the grades designated in the table on page 384. The word silt is probably akin to a number of Germanic roots meaning to sift or filter, compare German *seihen, to strain.*

*Clay.*—After consideration of a number of alternative terms, the term clay has been selected as most likely to be acceptable to geologists for the finest clastic sediments. A few geologists objected to the term on the ground that it implied plasticity or that it referred to a definite chemical composition. It is the view

[1] J. S. Flett, *Encyclopaedia Britannica*, 11th ed. (1911), Vol. XII, p. 382, and Vol. VI, p. 913.

Orth, *Bezeichnung des Korns nach der Größe des Kornes. Neues Jahrbuch für Mineralogie,* (1913); New York, A. G. Seiler & Company, p. 551, Volume for 1875.
J. S. Diller, *U.S. Geol. Surv., Bull. 150* (1900), p. 380.
*the Method of Elutriation, with Special Reference to the Thanet Beds of the Southern Side of the London Basin,* p. 2, London, Dulau & Co., 1920.
J. A. Udden, "Mechanical Composition of Clastic Sediments," *Bull. Geol. Soc. Amer.*, Vol. XXV (1914), pp. 655–744.

64–32 mm

32–16 mm

16–8 mm

Pebble gravel
Natural Size

FIG. 2

of the writer and of many other geologists that nearly all clastic materials of this grade consist largely of the hydrous aluminum silicates which make up the clay of the chemist and also that the material is always more or less plastic. There is, therefore, in his opinion a common ground for the geologist and chemist without an insistence on the use of the term clay for the pure chemical compounds kaolin or other minerals of this group.

ROCK TERMS

*Conglomerate.*—There are certain terms which are used with greater uniformity and less abuse than others. One of these is conglomerate. This term is very widely applied to rocks which are the consolidated equivalents of gravels. It is applied just as is the term gravel to rocks which vary widely in the sizes of their constituent particles. It seems desirable, therefore, to apply to it modifying adjectives as has been done with gravel, making the terms bowlder-conglomerate, cobble-conglomerate, pebble-conglomerate, and granule-conglomerate. The term granule-conglomerate is preferred to the term grit because grit has been used in England for both coarse- and fine-grained and angular-grained sandstones. The use of the term grit in the present sense seems therefore inadvisable.

*Sandstone.*—This term is generally used by geologists and no great change in its usage is here proposed. It is qualified by the adjectives very coarse, coarse, medium, fine, and very fine, and used for the consolidated equivalents of the various grades of sand. The term grit is not used for the coarser grade for the reasons stated in considering the term granule-conglomerate.

*Siltstone.*—After a consideration of a number of terms, siltstone was adopted by the writer as most acceptable for the consolidated equivalent of a silt. Shale, as proposed by some geologists, was considered objectionable because, in the usage of a majority of geologists at present, as well as etymologically, it is a structural term referring to the shelly structure of the rock rather than to the size of its grains.

*Claystone.*—The term argillite has already been used in another sense and the term shale is objectionable for the reasons given

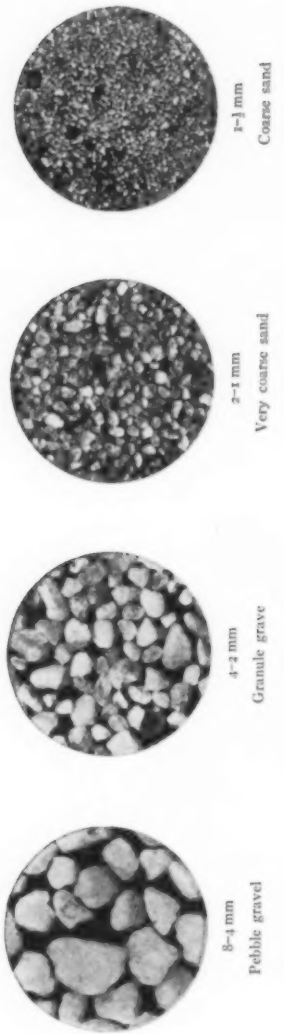
8–4 mm
Pebble gravel
4–2 mm
Granule grave
2–1 mm
Very coarse sand
1–½ mm
Coarse sand
½–¼ mm
Medium sand
¼–⅛ mm
Fine sand
⅛–1/16 mm
Very fine sand
1/16–1/32 mm
Silt
Natural Size

FIG. 3

above. The term claystone is here proposed as most satisfactory for the indurated equivalent of clay, as defined above.

### THE CLASS TERMS

The grade terms defined above for aggregates and for rocks are applicable, as the writer has pointed out in another part of this paper, to very few sediments of natural origin. Most such sediments are composed of particles of several or many grades and the names suggested above with definite numerical limits cannot properly be applied to them. This difficulty has been long recognized by students of sedimentary rocks and several schemes for meeting the difficulty have been proposed. Notable among these, because of the large amount of data published in accordance with it, is that of the United States Bureau of Soils which is given below.

### CLASSIFICATION OF SOIL MATERIAL

#### UNITED STATES BUREAU OF SOILS*

Soils containing 20% silt and clay:

| | |
|---|---|
| Coarse sand | more than 25% very coarse sand and coarse sand and less than 50% any other grade |
| Sand | more than 25% very coarse sand, coarse and medium sand, and less than 50% fine sand |
| Fine sand | more than 50% fine sand, or less than 25% very coarse sand, coarse and medium sand |
| Very fine sand | more than 50% very fine sand |

Soils containing 20–50% silt and clay:

| | |
|---|---|
| Sandy loam | more than 25% very coarse sand, coarse and medium sand |
| Fine sandy loam | more than 50% fine sand or less than 25% very coarse sand, coarse and medium sand |
| Sandy clay | less than 20% silt |

Soils containing more than 50% silt and clay:

| | |
|---|---|
| Loam | less than 20% clay, less than 50% silt |
| Silt loam | less than 20% clay, more than 50% silt |
| Clay loam | 20–30% clay, less than 50% silt |
| Silty clay loam | 20–30% clay, more than 50% silt |
| Clay | more than 30% clay |

* C. C. Fletcher and H. Bryan, "Modification of the Method of Mechanical Soil Analysis," *U.S. Dept. of Agric., Bur. Soils, Bull. No. 84* (1912).

The scheme of class terms presented below was devised by the writer after a somewhat extensive consideration of several more complicated classifications. These were characterized by more extensive use of the adjectives coarse and fine and by the use of many combinations and permutations of several grade terms.

These were all rejected in favor of the simpler plan here presented because of the seeming futility of attempting to make detailed quantitative discriminations by use of a verbal scheme. Such discrimination can be satisfactorily made only by graphic or tabular methods and the writer believes the simpler classification will be most generally acceptable and therefore most useful in the study of sediments.

The table shows only class terms for aggregates; the proper rock terms will be chosen and used in an analogous manner.

CLASS TERMS FOR SEDIMENTS

| Specifications by Grade | | Terms for Classes |
|---|---|---|
| Gravel > 80% | | Gravel |
| Gravel > sand > 10% | Others < 10% | Sandy gravel |
| Sand > gravel > 10% | Others < 10% | Gravelly sand |
| Sand > 80% | | Sand |
| Sand > silt > 10% | Others < 10% | Silty sand |
| Silt > sand > 10% | Others < 10% | Sandy silt |
| Silt > 80% | | Silt |
| Silt > clay > 10% | Others < 10% | Clayey silt |
| Clay > silt > 10% | Others < 10% | Silty clay |
| Clay > 80% | | Clay |

Certain materials of sedimentary origin but highly variable composition, notably glacial till, will not fall into any of the divisions of the table above. No attempt has been made to make an all-inclusive scheme. Till is known by its extreme range of mechanical composition and by definition, therefore, will not fit into so simple a classification. The test of any classification is in its applicability to natural objects. The terms here proposed were tested by reference to a large number of analyses made by Udden.[1] By inspection of about fifty of these chosen at random it was found that only the analyses of till did not accord with the specification given for one of the terms, and that each of the other

[1] J. A. Udden, *loc. cit.*

sediments tested was assigned to a suitable name differing only in added exactness from that used in the original description. In the table below are given nine of these analyses showing the

TABLE OF MECHANICAL ANALYSES BY J. A. UDDEN* SHOWING THE SEDIMENT NAMES APPROPRIATE TO THE CLASSIFICATION OF THIS PAPER

| Diameter in Millimeters | No. 75† Gravel † | No. 9 Sandy Gravel | No. 18 Gravelly Sand | No. 16 Sand | No. 68 Silty Sand |
|---|---|---|---|---|---|
| 64–32 | ..... | .2 | ..... | ..... | ..... |
| 32–16 | ..... | 14.0 | ..... | ..... | ..... |
| 16–8 | 3.3 | 13.2 | ..... | ..... | ..... |
| 8–4 | 65.9 | 20.0 | 6.1 | ..... | ..... |
| 4–2 | 26.0 | 14.4 | 7.4 | 1.7 | .2 |
| 2–1 | 3.0 | 11.4 | 3.6 | 24.4 | .3 |
| 1–1/2 | .3 | 18.2 | 7.2 | 49.2 | 7.2 |
| 1/2–1/4 | .2 | 5.6 | 36.8 | 8.3 | 17.9 |
| 1/4–1/8 | .7 | 2.6 | 37.4 | 14.8 | 48.7 |
| 1/8–1/16 | .3 | .2 | 1.2 | 1.0 | 8.4 |
| 1/16–1/32 | ..... | ..... | .2 | .4 | 13.2 |
| 1/32–1/64 | ..... | ..... | ..... | .1 | 3.2 |
| 1/64–1/128 | ..... | ..... | ..... | ..... | .7 |
| 1/128–1/256 | ..... | ..... | ..... | ..... | .1 |

* J. A. Udden, *loc. cit.*

† The numbers are those used by Udden in describing these sediments. The names are applied by the author of this paper according to the terminology here presented.

| Diameter in Millimeters | No. 70 Sandy Silt | No. 129 Silt | No. 131 Clayey Silt | No. 19 Silty Clay |
|---|---|---|---|---|
| 2–1 | ..... | ..... | ..... | ..... |
| 1–1/2 | .2 | tr. | tr. | ..... |
| 1/2–1/4 | .9 | tr. | tr. | ..... |
| 1/4–1/8 | 11.9 | tr. | .4 | 2.3 |
| 1/8–1/16 | 9.8 | 3.1 | 5.3 | 2.0 |
| 1/16–1/32 | 28.7 | 12.4 | 13.2 | 5.6 |
| 1/32–1/64 | 40.6 | 37.2 | 28.2 | 13.2 |
| 1/64–1/128 | 5.9 | 24.6 | 31.1 | 26.4 |
| 1/128–1/256 | 1.5 | 9.6 | 11.7 | 19.8 |
| 1/256–1/512 | .2 | 3.5 | 6.4 | 17.8 |
| 1/512–1/1024 | ..... | .9 | 2.4 | 10.0 |
| 1/1024–1/2048 | ..... | .2 | .8 | 2.3 |

composition, the number in Udden's table, and the name according to the present classification.

It will be pointed out that in order to name a sediment, one must first make a mechanical analysis. This is true to the degree

that it is true that microscopic study precedes the final naming of an igneous rock. However, as in the case of igneous rocks, field names based on simple megascopic inspection will be extensively used before detailed studies are made. It is believed that field names can be more accurately and expressively used if the principles and essential facts of a quantitative classification such as that here proposed are duly recognized.

# THE PRE-CAMBRIAN OF WESTERN PATRICIA[1]

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The purpose of this paper is briefly to summarize the results of two seasons' field work in western Patricia. Patricia lies in the extreme northwestern part of the province of Ontario, north of the Winnipeg, English, and Albany rivers, and their expansions, Lac Seul and Lake St. Joseph. The areas studied by the writer lie in the southwestern part of the district, and in a sense intervene between the classic areas studied by Lawson and others around the Lake of the Woods and Rainy Lake and a number of areas in the province of Manitoba, more recently studied by Bruce, Alcock, Moore, and others. Reconnaisance work had already been done in the Lac Seul region and northward along the Trout Lake, Wennasaga, Cat Lake, and other rivers by Dowling, A. W. G. Wilson, Camsell, and others, and the work of E. S. Moore in the region southeast of Lake Winnipeg had extended in a few places across the boundary of Manitoba into Patricia. The writer's work was done under the direction of the Department of Mines of Ontario in the Lac Seul region in 1919 and along the Ontario-Manitoba boundary from the Winnipeg River northward in 1921. No great originality or finality is claimed for the results as the work in both cases was confined to narrow strips of country immediately adjacent to the survey-lines or rivers which were traversed, and was not of such a nature as to allow of much areal mapping, which would afford a more complete knowledge of the relationships of the various formations than is possible by reconnaisance methods. There has not been time for microscopic study of the rocks in the boundary region, but their general character is evident and in most cases they have been determined already with accuracy by Moore, so that data are now available for at least a tentative

[1] Read at the Toronto meeting of the American Association for the Advancement of Science.

discussion of the relations of the two areas with one another and with the surrounding regions.

Lawson's general statement of the geological sequence of the Lake Superior region is as follows:

Algonkian
- Keweenawan
- Unconformity
- Animikie

Eparchaean Interval

Archean
- Algoman granites, gneisses, etc.
- Irruptive contact
- Upper Huronian
- Unconformity
- Lower Huronian
- Unconformity
- Laurentian granites, gneisses, etc.
- Irruptive contact
- Keewatin, Coutchiching } Ontarian

The Algonkian formations need not concern us for the purposes of this paper, although dikes exist in some of the areas considered which may be of Keweenawan age.

The region around Lac Seul and northward as interpreted by the writer from data collected in 1919 includes the following geological sequence:[1]

4. Younger porphyritic granite (Birch Lake River).

3. Older red and gray, sometimes gneissoid granites.

2. Upper sedimentary and schist series, including a (basal?) conglomerate, hornblende schist and other schists and possibly limestones and quartzites.[2]

Lower volcanic and schist series, including more or less altered volcanic rocks of rhyolitic, andesitic, and basaltic types, frequently ellipsoidal in structure, hornblende schists, in part ferruginous, and some jaspylite.

1. The lowest member of this succession is correlated with some confidence with the Keewatin of Lawson on account of its litho-

[1] But see the *Report of the Department of Mines of Ontario*, Vol. XXIX, Part 1 (1920), p. 181, for an alternative classification.

[2] The two last were not seen by the writer. See C. B. Dowling, *Geol. Surv. Can.*, Vol. VII, Part F.

logical resemblance, and because it is the oldest rock-formation present and antedates all of the granites with which it is in contact. Tentatively, however, the local name "Lac Seul Series" may be applied to it.

2. The series above the volcanics appears to be of predominantly sedimentary origin, with a basal conglomerate which has a

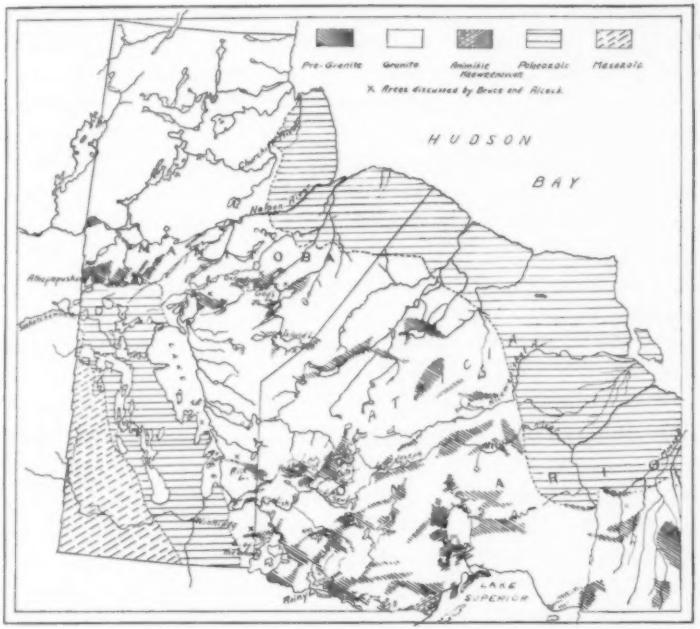


FIG. 1.—Map indicating pre-Cambrian areas mentioned in this paper

rather wide extent. It was observed especially at Slate and Birch lakes and was also reported by Dowling at Red Lake. In all three localities it is of practically identical lithological composition. Following Moore's example in the case of a similarly related series in eastern Manitoba, it was assigned to the Lower Huronian.[1]

[1] See *Ont. Dept. Mines Report*, 1920, p. 181, and compare *Geol. Surv. Can. Summary Report*, 1912, pp. 262 ff.

However, it affords no evidence of this so far as examined either by lying unconformably on post-Keewatin granites or by the presence of granite pebbles in the conglomerate. Therefore, its assignment to the Lower Huronian would imply either (1) that the granites of this region are all of post-Lower Huronian age, or (2) that the denudation of the great erosion interval which followed, or accompanied and followed, the intrusion of the Laurentian batholiths, was not here enough to uncover the batholiths before the Lower Huronian sedimentation began. If batholithic intrusion took place here in Laurentian time, the batholiths were not uncovered until much later perhaps between the Upper and Lower Huronian or even during the Eparachaean interval. Of these two alternatives, the second appears to the writer to be the less probable, judging by comparison with other regions not far distant. Neither alternative would demand the complete absence of Laurentian granite pebbles, since these might have been transported from a distance, and the quartz pebbles, which occur and which are well rounded in contrast to the angular chert-pebbles of Keewatin origin, probably are the residuals of such traveled material. For this series the name of "Birch Lake Series" is suggested.

3. The granite bodies which were observed in intrusive relations with the Lac Seul (Keewatin) series only are in two cases pink to grayish pink in color. In some parts, usually near contacts or where inclusions of older rocks are abundant, they display a gneissoid texture; in the central parts of the exposed areas and where relatively free from inclusions they are more massive. They are also in parts porphyritic. The rocks with which they are found in intrusive contact are frequently cut by dikes of pegmatite, while aplitic dikes as well as pegmatite occur within the mass of the granite itself. The rock is biotite granite with some hornblende, micropegmatite, and microcline, but no muscovite, tourmaline, or titanite. Another type of granite observed in intrusive contact with both the lower (Lac Seul or Keewatin) and upper (Birch Lake) schist series, is of gray color and is practically a binary granite with microcline as the chief feldspar. It also contains a little tourmaline, some oligoclase or andesine, and a little zircon and garnet. In the pegmatite dikes which accompany this granite tourmaline and

muscovite are largely developed. This type of granite occurs on the Wennasaga River from a point about ten miles above Slate Lake to Hailstone Lake, and also on Pakwash and Little Shallow lakes, where it has a syenitic phase with very little quartz. The same intrusion may be represented by dikes on a small island near the outlet of Lac Seul, which are composed of mica diorite.

Granites and gneisses of the red type were observed to the south of South Cove, Lac Seul, on the lower Wennasaga River, in the Cat River basin from Big Portage Lake to Springpole Lake, and on the lower Woman and Trout Lake rivers.

The relations in age between these two types of granite were not observable on the route followed by the writer. Both are post-Keewatin. The gray type is later also than the upper schist series, and both may be. If one is Laurentian and the other later, say Algoman, the Algoman is the gray granite.

There is, in addition, a coarsely porphyritic red granite intrusive in the red granite-gneiss of the Birch Lake River. It was not seen in contact with the schists, either upper or lower. This porphyritic granite is distinguished from the others by the presence of accessory titanite.

We pass now to the area studied during the summer of 1921 which lies along the Ontario-Manitoba boundary, a north and south meridian line, and is on the average about seventy-five miles (from sixty to one hundred) west of the field already described. Here we find as the oldest constitutents of the complex two series of rocks quite similar lithologically, and in their stratigraphic relation to each other, to the two series of schists already described.

1. The lower is a predominantly volcanic series which includes[1] greenstone (massive diabase and ellipsoidal lavas), quartz-porphyry, rhyolite, trachyte-felsite, green and gray schists due to alteration of these, and in one place a bed of white quartzite, partly iron-stained which occurs on the south side of the Winnipeg River a little west of the boundary, and has a total thickness of about thirty feet. To these rocks the name "Rice Lake Series" was given by Moore.

[1] E. S. Moore, *Geol. Surv. Can. Summary Report*, 1912, pp. 262 ff.

2. Lying above this is a predominantly sedimentary series whose most important rock is an extensive and thick conglomerate composed of the materials of the lower series with the exception of two constituents, a granite which does not appear within the area examined by Moore, and cherty fragments from iron-formations which were also not found in the lower series, although similar rocks are found in the upper series itself. These cherty fragments may have come from portions of the lower (Rice Lake) series since removed by erosion, or from parts farther east where they are known to occur in the lower series. There is a possibility that a gray gneissoid granite which may be seen on the Winnipeg River intruding the Rice Lake series may account for the granitic pebbles in the conglomerate. This gneissoid granite was not found in intrusive contact with the upper (Wanipigow) series and is older than the red and grayish-yellow or white binary pegmatitic granites which occupy most of the region, since these granites and the pegmatites derived from them intrude the older gray granite, and the red granite contains inclusions of it which, in many observed cases, have themselves included xenoliths of the Rice Lake (Keewatin) series. But while this is conclusive as to the relative ages of the various granites and the volcanic series, it is not conclusive as to the relative ages of the gray granite and the upper or Wanipigow series. The Wanipigow may then be older than any of the local granites and the pebbles found in its conglomerates may have been transported from a distance.

Comparing the Wanipigow conglomerate with that found in the upper or Birch Lake series of the Lac Seul region, it is true of both that they consist largely of pebbles derived from the volcanic rocks which immediately underlie them. Both also contain fragments of chert and jasper, which can be accounted for by the presence of iron-formation in the lower series of the eastern field, but are absent in that of the western area. In both, too, are pebbles of quartz. In the Lac Seul area these are hard to account for. They are well rounded and consist of a "sugary" white quartzite, partly stained to a yellowish color by iron oxide, which shows under the microscope "a granular texture of somewhat interlocking grains, no secondary enlargement of grains, slight amounts of bleached

biotite and brown iron oxide, very occasional grains of apatite and magnetite and flecks of kaolin." The quartz pebbles in the conglomerate on the interprovincial boundary are of a rather more glassy and massive appearance and must undoubtedly be described as vein-quartz. They cannot be accounted for as coming from the quartz veins which are now to be seen throughout the area, as these are of later age and owe their origin to the subsequent granite intrusions. But there is a bed of quartzite, as already described in the Rice Lake rocks, which outcrops on the Winnipeg River a little west of the Ontario-Manitoba boundary, and to this the pebbles of the conglomerate may in part be attributed, while others are no doubt derived from distant sources.

Taking everything into account there seem to be fairly good reasons for correlating the conglomerate horizons of the two areas and also the volcanics which underlie them, which may be taken as in all probability Keewatin. The conglomerate would then agree in age with the great erosion interval which has been found elsewhere after the Keewatin. In the region to the south and east, however, the extrusion of the volcanics, partly at least under water, was followed by mountain-building accompanied by granitic intrusion and denudation. In the area which is now under review there is no evidence of angular unconformity between the volcanics and the sedimentaries. The sedimentaries may have been largely subaerial in origin and in that case the history indicated is simply (1) emergence, (2) erosion of low-lying land to a surface of low relief, and (3) deposition of coarse materials perhaps on a piedmont plain. Some of these materials are of local origin while others (the quartzes, the cherts in part, and the granites) have been transported for greater distances.

A recent paper by Drs. Alcock and Bruce[1] sums up very well the results obtained from a study of a number of areas in northern Manitoba together with that studied by Moore to the southeast of Lake Winnipeg and the Star Lake area on the Ontario boundary farther south—in all ten localities. Their general conclusion is that the historical succession begins in most instances, as here, with very ancient volcanic extrusions. This was preceded in some cases by sedimen-

[1] *Bull. G.S.A.*, Vol. XXXII, pp. 267–92.

tation, as in the Rainy River region, "in others, sediments were interbedded with the volcanics, and in other areas these early periods of sedimentation continued long after the extrusion of lavas had ceased." In some cases a conglomerate exists which may mark an unconformity between the two divisions of this pre-granite series, as in the Lac Seul area; in others conglomerates occur at several horizons in the upper sediments, but some of them are not of great lateral extent, while graywackes and arkoses indicate little transportation or sorting and possibly subaerial deposition. In some places cross-bedded deposits are interpreted as ancient deltas.

The whole would agree with the hypothesis that while post-Keewatin mountain-building occurred in the Rainy Lake field and others farther east, the country to the north and west, although elevated above sea-level, remained in the condition of a piedmont costal plain and, not being folded, was not intruded by granites of Laurentian age.[1] At the same time it was covered with the ill-sorted products of mountain erosion, largely through the action of torrential streams. At a later time, however, this region was subjected to folding, batholithic intrusion, and subsequent deep erosion. This was followed in some localities by one or more periods of deposition with intervening folding and erosion, after which long erosion had produced peneplanation before the advance of the Ordovician sea.

This would agree very well with the facts observed by the writer, except that the later sediments following the first folding (Upper and Lower Missi, Churchill quartzites, etc.), do not occur in the region on which this paper is based.

[1] An exception to this is made in the case of the Athapapuskow area in northwestern Manitoba which would appear to limit the area in which the Laurentian may be absent on the northwest.

# Petrological Abstracts and Reviews

CHARLES H. BEHRE, JR.

Ferguson, J. B., and Merwin, H. E. "The Melting Points of Christobalite and Tridymite," *Amer. Jour. Sci.*, XLVI (1918), 417–26, figs. 2.

A description of experimental methods employed in testing the melting points of these two minerals. A high-temperature furnace, built on the cascade principle, and capable of maintaining a temperature of 1700° for several hours, is described. By means of this furnace quartz has been inverted directly through dry heat alone. The melting point of tridymite has been determined (for the first time) as 1670°±10° C.; that of christobalite has been redetermined; it is 1710°±10° C. Christobalite is stable at higher temperatures than tridymite as determined earlier by Fenner.

Ferguson, J. B., and Merwin, H. E. "Wollastonite ($CaO.SiO_3$) and Related Solid Solutions in the Ternary System Lime-Magnesia-Silica," *Amer. Jour. Sci.*, XLVIII (1919), 165–89, figs. 8.

A further experimental study of the liquidus curves for the system of these three oxides, though not completely quantitative, yet confirms the earlier work with the same system, demonstrates the existence of solid solutions of diopside up to the amount of 16 per cent in pseudowollastonite and diopside, and of åkermanite in wollastonite and pseudowollastonite. A new compound—$5\ CaO.2MgO.6SiO_2$—is reported. The paper contains also a fairly complete discussion of results obtained in the curves derived, and photographs of the solidus-liquidus concentration-temperature models.

Ferguson, J. B., and Merwin, H. E. "The Ternary System $CaO.MgO.SiO_2$," *Amer. Jour. Sci.*, XLVIII (1919), 82–123, figs. 19.

This is the most complicated system of any that can be constructed of three of the four oxides, CaO, MgO, $Al_2O_3$, and $SiO_2$. Försterite, diopside, enstatite, tridymite, cristobalite, lime, magnesia, pseudowollastonite, and two compounds of the three oxides were obtained. Solid solutions of five types were also recognized in crystalline form; these included clino-enstatite-diopside solutions, pseudowollastonite solutions of varying composition, wollastonite solutions, solutions of an unnamed compound of the three oxides, and menticellite solu-

tions. Scholler's åkermanite could not be prepared, but $5CaO.2MgO.6SiO_2$ and $2CaO.MgO.2SiO_2$ were recognized for the first time. The tridymite-cristobalite inversion temperature is essentially 1470° C., but measured with difficulty because of the great sluggishness of the inversion.

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FERGUSON, J. B. "The Oxidation of Lava by Steam," *Jour. Washington Acad. Sci.*, IX (1919), 539–46.

Demonstrates experimentally that the formerly generally supposed oxidizing power of steam in lavas is not effective. Hence volcanoes may give off lava bearing ferrous iron and yet discharge large amounts of steam.

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FLÖRKE, WILHELM: *Über die kunstliche Verwitterung von Silikatgesteinen unter dem Enfluss von schwefliger Säure.* Giessen, 1915. Pp. 32.

This is a study of the action of sulphur dioxide on coarse-grained igneous rocks. Experiments were carried on in the presence of water. All types of rock, varying from granite to gabbro, were attacked by the $SO_2$ vapors. The ferro-magnesian minerals were most corroded, hence the basic rocks also suffered most. Soluble sulphates of aluminum, iron, manganese, calcium, magnesium, sodium, and potassium were produced, as well as insoluble hydroxides of aluminum and iron.

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FOYE, WILBUR GARLAND: "Geological Observations in Fiji," *Proc. Amer. Acad. Arts and Sci.*, No. 1, LIV (1918), 1–145, bibliography, figs. 40, pls. 1; in two parts.

A summary of the geology and petrology of the Fiji Islands is here presented. The group consists of two larger islands, Viti Levu and Vanua Levu, having central cores of deeply eroded plutonic rocks and possibly representing an earlier continental mass, and of several smaller fringing land masses. Four periods of vulcanism are recognized, the first being rhyolitic, the last basaltic, and the two intermediate ones andesitic. On Viti Levu a series of Miocene (?) sediments is much folded and overlain on the coastal plains by gently dipping post-Tertiary beds. On Vanua Levu are Pleistocene or recent coastal plain limestones and volcanics. Here subsidence has been generally accompanied by reef formation. An extended discussion of the coral reef question is given and a modification of Darwin's hypothesis thought to be favored in some measure.

The history may be summarized as follows:

9. Subsidence.
8. Basaltic intrusions and extrusions.
7. Uplift and erosion of (6).
6. Subsidence, with the deposition of about 150 feet of limestones and marls.

5. Second period of volcanic eruption, with subsequent erosion.
4. Uplift and erosion of (3).
3. Subsidence and deposition of limes, sands, and clays.
2. Andesitic lavas extruded, later eroded.
1. Plutonic intrusives, eroded to late maturity.

The first part of the paper describes the general geology of the islands; the foregoing is a brief summary. The second part discusses the petrography of the region studied. The important sediments are chiefly calcareous, but some conglomerate is known—river gravel, with bowlders of all sorts, and a calcareous conglomerate with over 50 per cent igneous bowlders but much shell-waste in the cement. The igneous rocks described are chiefly andesites and basalts, of which the latter preponderate in the descriptions.

Some of the extrusions were submarine, marked generally by the presence of hornblende; this character almost appears to be diagnostic of the subaqueous origin of such flows as bear it. Another interesting feature is the persistent association of hypersthene and hornblende.

The first andesitic period is recognized only on the two large islands. The flows of the second andesitic period are widespread and may be essentially synchronous in origin with some basalts and rhyolites. The lavas of the basaltic period, again, are more limited in their distribution. In general, differentiation in Fiji progressed from acid to basic. Volcanic vents have been singularly persistent, the basaltic flows seldom or never forming cones of their own. Ten rock analyses are presented, but no modes are given and only a few of the rocks are classified according to the norm system.

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GOLDSCHMIDT, V. M. *Die Gesetze der Gesteinsmetamorphose, mit Beispielen aus der Geologie des Südlichen Norwegens.* Christiania, 1912. Pp. 16, fig. 1.

A concise application of the laws of thermodynamics to metamorphism. The "mineralogical phase rule" states that in a stable combination as many minerals may be formed as there are variables in the system. Thus in a mixture of silica, magnesia, and alumina only three minerals may be developed. The conditioning agents in contact metamorphism are pressure and temperature. By plotting the pressure horizontally and the temperature vertically, various fields are obtained which are either gradational or sharply marked off from each other. The melting temperatures of the more refractory minerals limit the phase-curve above. The effect of pressure is well illustrated by grossularite, which requires a higher pressure to maintain its identity at high temperatures than at low ones; its compact atomic structure is also favorable to stability at high pressures. Separate curves for each system may be prepared by applying the third principle of thermodynamics, Nernst's theorem; the approximate formula used in calculating the curve is from the same investigator. Such a curve applied to the system $CaO.SiO_2.CO_2$ yields a change

from calcium carbonate and quartz at lower temperatures (mean about 900° C.) to wollastonite and carbon dioxide. This and similar rules are exemplified by the crystalline schists of the Christiania region.

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GOLDSCHMIDT, V. M. *Das Devongebiet am Röragen bei Röres.* With a paleontological supplement: NATHHORST, A. G. *Die Pflanzenreste der Röragen-Ablagerung.* Christiania, 1913. Pp. 27, pls. 5, maps 2, figs. 3.

This is a report on the areal and structural geology of an area measuring about 10 by 7 kilometers in south-central Norway, bounded on the north by the Lake of Betnen, on the south by the Lake of Feragen. The sedimentaries shown here are Cambrian, Ordovician, and Devonian, the last composing by far the greater part. Granite, augen-gneiss, saussuritized gabbro, and basic peridotite-serpentines are the igneous rocks. Chromite has been mined in the last-named rock. The Devonian beds overlie unconformably the eruptives and older sedimentaries; they consist of conglomerates, sandstones, and slates. An especially interesting member of the Devonian sequence is a 200-meter-thick serpentine conglomerate, of which the angular bowlders resemble breccia-fragments of serpentine; at its base it goes over locally into white magnesite. The total thickness of the Devonian is about 400–500 meters.

Faulting has affected the pre-Caledonian sediments, and this was followed by a period of intrusion from which date the eruptive rocks mentioned above. The pre-Devonian beds dip toward the northwest.

Devonian beds, however, have a general southeasterly dip. These sediments were probably deposited in a basin or basins of limited extent, formed and filled during the middle Devonian.

Illustrative plates and a brief description of the Devonian floras of the region accompany the report.

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GOLDSCHMIDT, V. M. "Über einen Fall von Natronzufuhr bei Kontaktmetamorphose," *Neues Jahrb.*, XXXIX (1914), 193–224, pl. 1.

A study of contact metamorphism in sandstones of Norway. The unmetamorphosed sandstones are somewhat arkosic (microperthite, albite, orthoclase, and microcline are the feldspars) and flakes of muscovite and chlorite are also present; the matrix is calcareous or argillaceous. These sandstones are Devonian or Silurian in age. When metamorphosed they normally become biotite-rich quartzite or even hornfels. Wollastonite is commonly developed. In other instances secondary potash feldspars, sometimes intercrystallized with plagioclase, appear in the matrix. Besides quartz, a pyroxene (hedenbergite) is very common. This description characterizes the normal type of metamorphism.

An entirely distinct type of metamorphism, common along the borders of pegmatite dikes, is conspicuous in the presence of aegirite and riebeckite, as well as of long, needle-like titanite crystals. The latter, as well as the soda-rich pyroxene and amphibole, are attributed to an increase in soda-content, with a corresponding decrease in calcium oxide. The formation of aegirite and riebeckite takes place especially in the absence of alumina.

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GOLDSCHMIDT, V. M. *Geologisch–Petrographische Studien in Hochgebirge des Südlichen Norwegens: III, Die Kalksilikatgneise und Kalksilikatglimmerschiefer des Trondhjem-Gebiets*, Christiania, 1915. Pp. 37, pls. (and maps) 2, table 1.

This is a summary of investigations in the zone of the Gula gneisses and slates of the Trondhjem district, Norway. The Gula group is probably of Silurian age. The rocks are highly metamorphosed, and the particular facies here studied are those rich in calcium silicates. Several zones of the schists are recognized, varying in their chlorite and biotite content. The results of extreme metamorphism may be summarized as follows: (*a*) Highly calcareous rocks lose their biotite content, this being replaced by plagioclase, amphibole (or pyroxene), and potash feldspar; or, (*b*) If poor in calcium oxide, the rocks are converted into a biotite-plagioclase rich slate, with varying amounts of quartz. In the former case the rock texture and constituents vary markedly with variations in degree of metamorphism. The latter type may be readily shown to be of sedimentary origin by means of microscopic study, corroborated by chemical analysis. Methods given in the text for calculating the theoretical constitution of these meta-sedimentaries are most instructive.

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GOLDSCHMIDT, V. M. *Geologisch-Petrographische Studien im Hochgebirge des Südlichen Norwegens: IV, Übersicht der Eruptivgesteine im Kaledonischen Gebirge zwischen Stavanger und Trondhjem*. Christiania, 1916. Pp. 140, pls. (and maps) 7, table 1, figs. 2.

Reports the petrologic findings in an area about 600 kilometers long lying between Stavanger and Meraker, in southern Norway. This area bears igneous rocks of all sorts, from acid to basic. It is impossible to treat these as though they were all products of a single magmatic province; more probably they belong to three separate groups, as follows: (1) Green lavas, tuffs, and intrusives—the differentiation products being chiefly basic; (2) Anorthosite-charnokite rocks, with numerous differentiation products; and (3) Tonalite-granodiorite magmas, with many differentiation products. Some few of the rocks, indeed, do not even fit into such a classification.

In the first group are lavas, tuffs, agglomerates, and dike-rocks. Pillow-lavas are common. The intrusives of this group are gabbros and olivine-rich rocks. These are often saussuritized, uralitized, or converted into serpentine. Analyses of members of this class, as well as of the two others, are presented. The green lavas probably range in time from the upper part of the Ordovician into the Silurian; they are apparently homologues of the greenstones of England and Wales, which, however, were extruded at a slightly earlier date.

The anorthosite-charnokite rocks vary greatly in character. Some are typical gabbros and norites, others bear a little potash feldspar. Uralitization is common here.

Masses of pyroxenites and peridotites also belong to this period; these generally appear as lenses enclosed in basic or intermediate masses of more recently consolidated magmas of the same group. Another type of rock found here is labradorite-rich, hypersthene-bearing "labradorfels" (=anorthosite). All the above rocks of this segregation group are basic. There are also norites and mangerites; hypersthene-syenites represent a gradation toward the more alkalic end of the series; and finally acid rocks are represented by granites—hypersthene-granite (birkremite), commonly showing droplet-like plagioclase within the potash feldspar, augite-granite, diopside-granite, aegirite-granite, amphibole-granite, and biotite-granite, the latter two forming the commonest acid rocks of the group. Pegmatites and dike-rocks are common, and the latter range from acid to basic (peridotites). The sequence in the anorthosite-charnokite group is known with certainty to be (1) pyroxenite-peridotite, gabbro and norite, (2) norite, mangerite, and labradorite, (3) pyroxene-syenite, monzonite, and granite.

These anorthosite-charnokite rocks appear to have played a noteworthy part in the diastrophism of the region. They are assigned to early Caledonian age.

The third group studied comprises pyroxenites, peridotites, and gabbros; intermediate rocks, too, such as diorites, hypersthene-mica-diorites, and a peculiar type newly called "opdalite," which appears to be essentially a quartz-diorite. The acid phase is represented by "trondhjemite," (new name) which Kjerulf calls an oligoclase-granite, and which might as well be characterized as a granodiorite. Associated with these rocks are some dike-rocks, which incline generally toward the acidic; thus trondhjemite-porphyries, -aplites, and -pegmatites are recognized. The porphyritic phases occur already as borders of the larger intrusive masses.

A noteworthy fact is the sharp boundary of these aplites against the schistose basic country rock. This is explained by applying the principles of differentiation through fractional crystallization. A granite which has differentiated and achieved stability through having the basic constituents of the mother magma crystallize out, cannot resorb similar basic components; a magma can only assimilate the country rock when the mineral constituents of the latter have not been previously lost by differentiation in the mother magma.

Most of the rocks of the trondhjemite character are laccoliths or laccolithic. They all appear to be post-Ordovician; they may be described in general as of Caledonian (Upper Silurian) age.

Many rocks do not definitely fit into any of the foregoing three groups. These include pyroxenites, gabbroid types, basic and normal diorites, tonalite, granites, and their aschistic and diaschistic differentiates. This group may, if the sequence be as given above, indicate progressive differentiation. They occur south of the Trondhjemfjord. Granites are found on the west coast, too, and here are definitely assignable to Caledonian age, but cannot be readily placed in a magmatic province. Some augengneisses are also assigned to the same period.

As to the consanguinity of the three main groups recognized above, nothing definite can as yet be stated; surely the relationship is not as close between the separate groups as within each group. Each group, however, illustrates beautifully the differentiation-parallelism of separate magmas. Whether or not they *are* related might perhaps be answered by calculating the general composition of each group from a study of the rock-components. Data for such a calculation is, in the opinion of Doctor Goldschmidt, not yet sufficiently complete to undertake any generalizations. This is unfortunate, for here is a large geographic province which might furnish the best of examples for a study of magma-relationships and petrographic provinces in time if not in space.

Rocks similar to the green lavas occur in Scotland, and others like the Bergen-Jotun-granites (Group 2, above) are recognized from Sweden. The third group (called by Goldschmidt the opdalite-trondhjemite group) is undoubtedly represented in southern Scotland by the Galloway granite of Peach, Horne, and Teall, the age of which is less than the Ludlow and greater than the Old Red.

The writer seeks to draw analogies between the petrographic character of the rocks in the Stavanger-Trondhjem district and those elsewhere, especially in the Alps.

Twenty-two analyses of typical representatives of the several groups are appended, and many more, sometimes recalculated, are incorporated in the text.

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GOLDSCHMIDT, V. M. *Geologish-Petrographische Studien im Hochgebirge des Südlichen Norwegens: V, Die Injektionsmetamorphose im Stavanger-Gebiete.* Christiania, 1921. Pp. 142, pls. 15, map (with separate legend) 1, with numerous tabulated analyses.

The rocks in this district are of several periods. At the base of the section are pre-Cambrian rocks, unconformable below Cambro-Silurian deposits. The latter consist of phyllites of Cambrian and lower Ordovician age and of green slates of the upper Ordovician and Silurian. These are followed by eruptives

of Caledonian age, which are partly green lavas, partly members of the opdalite-trondhjemite group discussed in a previous paper. Locally on the borders of the district are conglomerates, arkoses, and sandstones essentially of Downtonian age (Upper Silurian). Still younger dikes of diabase traverse the other rocks, and Quaternary sands and clays, partly glacial, are the last deposits to be laid down.

The pre-Cambrian rocks are chiefly granitic, with lesser amounts of amphibolites. Structurally they represent a major syncline, the axis of which parallels the trend of the Caledonides, i.e., runs northeast-southwest. The phyllite division of the Cambro-Silurian is definitely assigned to the Cambro-Ordovician on the basis of fossils occurring outside the area; it begins with a basal conglomerate, and passes into phyllites and calcareous strata, with local increase in sandy content. This phyllite division is at least 300 meters thick.

The green saltes are assigned to the Silurian also on the basis of fossil findings. These "slates" bear sandstones and conglomerates (rarely) and considerable amounts of limestone and dolomite (which may have been derived metasomatically from limestones), but metamorphosed clayey deposits are predominant among the sediments. Eruptive rocks are highly metamorphosed, so that they cannot always be assigned with certainty to volcanic origin.

Sedimentary rocks are known from the Caledonian; they consist of conglomerates, typical sandstones, arkoses, and similar types, derived largely from the pre-Caledonian and Caledonian effusives. Hence also these actually follow the Caledonian opdalite-trondhjemites and green lavas. A description of the first of these two Silurian types is to be found in the preceding review; both basic and acid rocks are known, the latter including adamellite, granite, and quartz-pegmatite.

The Cambro-Silurian rocks were deposited on a peneplained surface. This period of sedimentation was followed by one of intrusion—that of the opdalite-trondhjemite group, either synchronously with or slightly preceding the Caledonian mountain-building, during which sediments and intrusives alike were folded and fractured, the magmas perhaps being deformed even before complete congealing. Finally in late Caledonian times there was extensive faulting of all the rocks of the Stavanger District.

A study of the opdalite-trondhjemite masses of Stavanger demonstrates that the larger intrusives are limited to the boundary between the phyllites and the overlying green slates. These actually represent one type of structure, whereas an entirely different type is indicated by flat-lying masses of intrusives that seem to have been more severely displaced during cooling. In the Stavanger District the two types of structures, one representing igneous rocks cooled in place, the other those cooled after some dynamic action, lie close together; of these the distorted and "dynamo-transported" masses are by far the more common.

After this general discussion of the geology of the region, the writer proceeds to a description of the metamorphism that has affected the rocks, with special

regard for the injection-metamorphism that borders the opdalite-trondhjemite type of rocks. The clayey sediments have undergone regional metamorphism ranging in its products from the mere development of good cleavage, through the development of garnet-mica-schists, and finally the growth in these of basic plagioclase and of pyroxenes.

Most distantly from the borders of the acid masses the phyllite becomes altered to garnet; farther in toward the intrusive this is replaced by biotite, thus presenting an order that is the reverse of that more commonly observed. There is also a progressive increase in sodium content as the intrusions are approached. Closer yet microperthite makes its appearance. These rocks are in turn altered to injected mica-schists and gneissic mica-schists; the "injected" schists are not so in the sense that a liquid magma has been forced inward along the lines of schistosity; injection, as here used, implies rather a metasomatism, with a relatively small addition of extraneous material.

The upper Silurian green slates, too, form significant "injection schists." Even the basic differentiates in the opdalite-trondhjemite series have undergone some contact alterations, because affected by the later acidic intrusions.

Various types of metamorphic rock are described in detail; these include quartz-muscovite-chlorite-phyllite, quartz-muscovite-chlorite-garnet-phyllite, quartz-muscovite-biotite-garnet-phyllite, chloritoid-slates, and albite-porphyroblastic schists. Transitions between these and "augengneisses" are also known. When acid material is added by injection, the albite-porphyroblastic rocks are altered to injection-(injected)gneisses. These are partly bedding-plane injection types, with marked parallelism in the texture of the crystalline injected rock, partly vein-injected gneisses, and augen-gneisses (which are attributed also to injection of clay slates by the more acid rock).

Much of the alteration is due especially to the addition of quartz, water, and soda. These may have been brought in as soluble sodium silicate.

The metamorphism here described is compared with that elsewhere in Europe and also with that in the Christiania District, which has been studied in detail. In the latter instance it is interesting to note the far greater regional distribution of the contact phases, attributed by Goldschmidt to the greater water content of the effective magmas. In the Stavanger District probably the most conspicuous thing is the extensive contact metamorphism of *siliceous* sediments. Into the same class of metamorphism, due essentially to chemical differences between the country rock and the "magma milk," falls that described by Brauns under the name of "pyrometamorphosis."

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GORDON, SAMUEL W. "Ordovician Basalts and Quartz Diorites in Lebanon County, Pennsylvania," *Proc. Acad. Nat. Sci.*, Philadelphia, Nov., 1920. Pp. 354–57, figs. 5.

Includes the first report of Paleozoic volcanic rocks in the form of a basalt flow, from Lebanon County, Pennsylvania. Intrusive into the Martinsburg

shale are sills and dikes of quartz diabase, to the northwest of which lie the interbedded basaltic flows. The quartz-diabase is a fine-grained dark greenish rock becoming very fine-grained at the contact; it may bear phenocrysts of augite, attaining a length of a centimeter; the texture is diabasic or ophitic, the labradorite being quite zoisitized.

The basalt is brecciated or tuffaceous and amygdaloidal, hence the flows were probably subaqueous; under the microscope the basalt breccia shows as a perlitic, dark greenish glass.

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GUILD, F. N. "A Microscopic Study of the Silver Ores and Their Associated Minerals," *Econ. Geol.*, XII (1917), 297–353, pls. 11.

This paper represents a summary of rather extensive work done by Mr. Guild on silver ores from many localities, both here and abroad. The characteristic early minerals of silver deposits are pyrite, sphalerite, and arsenopyrite. These are chiefly hypogene in origin, though the first may also occur as a secondary mineral. They are commonly followed by the deposition of argentiferous galena and tetrahedrite; the order of deposition is arsenopyrite, pyrite, sphalerite, tetrahedrite, chalcopyrite, and galena. The later silver minerals that are discussed include stromeyerite, which exhibits exceedingly close "pseudo-eutectic" intergrowths, that may actually be eutectic in nature, pyrargyrite and proustite, stephanite, polybasite, argentite, and native silver. The latter certainly forms in some cases as a result of the breaking down of complex silver minerals. Other sources of silver are also briefly considered—cerargyrite and the rarer minerals huntlinite (silver arsenide), dyscrasite (silver antimonide), brogniardite (a complex sulphide of silver, lead, and antimony), and schirmerite (bismuth-silver-lead sulphide). Variously associated with the silver are chalcopyrite, bornite, chalcocite, and covellite. Commonly associated cobalt and nickel minerals are smaltite, niccolite, and breithauptite.

The predominant gangue minerals found with silver are carbonates—notably in the lead-silver type of ores; this indicates a tendency for such ore-minerals to come from neutral or alkaline solution, as carbonates could not be developed in acid solutions. The gangue minerals mentioned are calcite, dolomite, siderite, rhodochrosite and barite.

Excellent hints as to methods for distinguishing silver minerals microchemically are presented, a subject so far neglected only too often. Good manuals for the ore-geologist are indeed rare, and good manuals dealing with the microscopy of silver minerals are wholly lacking.

The paper contains interesting discussions of graphic intergrowth, of "enrichment" of silver ores, and of the composition of some important silver minerals. A table presents the investigator's ideas regarding the sequence of deposition of double salts of silver and other metals.

# REVIEWS

*Proceedings of the Coal Mining Institute of America.* Thirty-third Annual Meeting, Pittsburgh, Pennsylvania, December, 1919. Pp. 158.

In an article on the "Future Development of Fuels," Henry Koeisinger, fuel engineer, United States Bureau of Mines, discusses those modes of coal consumption that utilize most fully the energy latent in the fuel, namely by-product production of coke, the use of powdered coal, and the use of so-called "colloidal fuel," a mixture of powdered coal and fuel oil. Electrification of railroads and better combustion of coal in the commoner methods of utilization come in for discussion.

Pages 34 to 43 are devoted to an excellently illustrated article by Reinhardt Thiessen of the United States Bureau of Mines, on the "Constitution of Coal through a Microscope."

Pages 89 to 101 are devoted to a paper by H. C. Ray, professor of ore dressing at the University of Pittsburgh, on "Modern Practices in the Washing of Coal," illustrated with nine text figures.

E. S. B.

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*Report on Some Sources of Helium in the British Empire.* By J. C. McLennan and Associates. Canada Department of Mines, Mines Branch, Bulletin 31, 1920. Pp. 72.

Shortly after the commencement of the war, it became evident that, if helium were available in sufficient quantities to replace hydrogen in naval or military airships, the losses in life and equipment arising from the use of hydrogen would be enormously lessened. Helium, as is known, is most suitable as a filling for airship envelopes, in that it is non-inflammable and non-explosive, and, if desired, the engines may be placed within the envelope. By its use it is also possible to secure additional buoyancy by heating the gas (electrically or otherwise), and this fact might possibly lead to considerable modifications in the technique of airship maneuvers and navigation. The loss of gas from diffusion through the envelope is also less with helium than with hydrogen, but, on the other hand, the lifting power of helium is about 10 per cent less than that of hydrogen.

Early in 1915 Dr. J. C. McLennan, head of the department of physics in Ontario University, was requested by the Board of Invention and Research, London, England, to investigate the helium content in various natural gas supplies within the British Empire. As a result of these investigations it has been shown that the largest source of supply of helium at present known within the empire is located in Canada. Commercial methods of separating helium from the other components of natural gas were developed as a result of the preliminary investigations, and considerable progress was made toward the development of methods for the production of helium on a commercial scale, as a result of which it was shown that helium could be produced at a cost of somewhat less than $0.25 per cubic foot at normal pressures and temperatures.

As a result of a large number of analyses, which are given in this report, it was found that the richest natural gases in Canada contained about 0.33 per cent of helium—a percentage believed to be sufficient for profitable commercial extraction, but considerably lower than the percentages which characterize the gases from a number of wells in Kansas, where the helium content ranges from 1.5 to 2 per cent. Analyses are given of natural gases from Ontario, Alberta, and British Columbia.

As a supplemental investigation, a study was made of the radioactivity of a number of these gases. It was found that when the gases escape from the well they usually contain the emanations of radium and thorium. The thorium emanations are very short-lived, but the decadence in the radium emanations is much slower. Measurements of the radioactivity of a number of gases were made, the method used involving the deduction of the amount of radium emanation from measurements of the increase in electrical conductivity which the presence of radium emanations imparts to the gas.

E. S. B

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*Potash Recovery at Cement Plants.* By ALFRED W. G. WILSON. Canada Department of Mines, Mines Branch, Bulletin 29, 1909. Pp. 34, pls. 10.

Considerable interest was awakened during the war by the cessation of potash imports from Germany in all possible substitute sources in the United States and Canada. The report under review is the outcome of investigations started then by the Canadian War Trade Board.

The wisdom of peace-time development of our slender resources of potash-bearing brines may be challenged. Much might be said in

favor of allowing such reserves to remain in the ground pending the next national emergency. But the recovery of potash as a by-product of cement manufacture and from iron-blast-furnace dust is utilization of raw material and of heat energy that otherwise would be wasted and should command the support of all conservationists. Such processes have the added advantage of minimizing the dust nuisance around cement plants, which is a danger to the health of employees and is detrimental to crops in agricultural districts. It has been estimated that in the United States, if all cement plants were equipped to recover potash salts, potash equivalent to over one-fourth of our normal imports of German potash salts could be recovered.

The report under review outlines briefly the principles underlying the recovery processes and describes in outline the equipments at all the plants in the United States and Canada where potash recovery has thus far been practiced. At the temperatures of 1,400 to 1,500° C. obtained in cement kilns, the potash-bearing silicates are in part decomposed, potash reuniting usually with the sulphate radical to form potassium sulphate, or to a lesser extent with the chloride radical to form potassium chloride—salts which are soluble and which pass into the stacks with the gases, where they can be recovered by spraying the gases or precipitating the dust by the Cottrell electrical process. The quantity of potash salts produced varies from 2 to 7 pounds per barrel of Portland cement.

Installation of potash-recovery equipment does not involve any changes in the processes of cement manufacture, nor does it affect the grade of the cement produced.

The report closes with a complete bibliography.

E. S. B.

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*Timiskaming County, Quebec.* By M. E. WILSON. Canadian Geological Survey, Memoir 103, Ottawa, 1918. Pp. 197, pls. XVI, figs. 6, map.

This is a concise, detailed report of the results and conclusions of geological field work carried on for a number of years in Timiskaming County, together with a theoretical discussion of some of the more important problems of the area.

Timiskaming County has an area of approximately 20,000 square miles and lies on the east side of the boundary line between Ontario and Quebec and east and northeast of Lake Timiskaming. The National Trans-

continental Railway crosses the northern part of the county and this part can be easily reached.

This area lies within the Laurentian Plateau and is characterized by a remarkable uniform relief but the surface in detail is irregular. The minimum elevation is almost everywhere more than 800 feet, and the maximum less than 2,000 feet; thus the range in elevation is seldom greater than 1,200 feet. The northern part of the county is drained by the Bell and Harricanaw rivers flowing into James Bay, and the southern part by the head waters of the Ottawa River flowing into the St. Lawrence River.

A very widespread base-level represented by the erosion surface between the basal complex and the Cobalt series or other late pre-Cambrian formations is still preserved. So also is the peneplain developed before the advance of the early Paleozoic seas. Since these early Paleozic rocks are approximately horizontal, all the movements of this great area since that time have been due to regional uplift, warping, and faulting. Of these, faulting has been the most important.

Another very noticeable physiographic feature is the large number of linear valleys, which, when classified according to general direction, fall into three groups striking approximately northwest, north, and northeast. The evidence in favor and against the faulting hypothesis of origin for these valleys is given. The faulting hypothesis most easily accounts for these valleys, and is assumed to be the most reasonable explanation, although very little field evidence of faulting along the valleys has been found. These valleys are post-Silurian and pre-Glacial.

The rocks occurring in Timiskaming County fall into the following four divisions: (1) the basal complex, (2) the Cobalt series and associated intrusives, (3) the Ordovician and Silurian sediments, and (4) Quaternary Glacial and post-Glacial gravels, sands, and clays. Detailed lithologic descriptions are given of the many different rock types represented, with notes on the structure and origin of many of the metamorphic types. Based on lithology and origin, the rocks of this region may be grouped into three parallel belts running in a northeasterly direction. Sediments belonging to the Grenville series characterize the south belt; banded gneisses mostly of igneous origin, the central belt; and volcanics and clastic sediments, the Pontiac series, the north belt. In the southern part of Timiskaming County inclusions of Grenville sediments are found along the southern edge of the banded gneiss belt. Because of the many difficulties and uncertainties of long-distance correlation of very intensely metamorphosed pre-Cambrian formations outlined in chapter IV, no

attempt is made to correlate the Grenville sediments south of the belt of igneous rocks, with the Pontiac series north of this belt, although the three possible theoretical relationships are given.

Chapter VI deals with "Special Problems of the Timiskaming Region," a brief summary of the literature together with evidences and conclusions reached from a detailed study of this particular area. Conclusions are given concerning such problems as the "Origin of Pillow Structure," "Origin of Ferruginous Dolomite," "Origin of Banded Gneisses," "Origin of the Cobalt Series"; a general discussion of the "Clay Belt of Northern Ontario and Quebec," and the "Origin, Extent, and Duration of Lake Barlow and Lake Ojibway."

In chapter VII the gold, silver, and molybdenite prospects of the area are described. When this report was written none of these prospects was developed to the state of producing mines. The great mantle of post-Glacial lake clays which cover a large part of the county makes prospecting difficult.

In a brief review of this Memoir it is impossible to give an adequate summary of the many important problems of pre-Cambrian geology discussed. This Memoir will be found useful to anyone interested in the problems of pre-Cambrian geology of Quebec and Ontario.

J. F. W.

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*The Paleozoic Rocks of the Canton Quadrangle.* By G. H. CHADWICK. New York State Museum Bulletin, Nos. 217, 218. Albany, N.Y., 1919. Pp. 60, pls. 12, figs. 3, maps 1.

Across the northern third of this quandrangle the Paleozoic rocks form the country rock, while in the southern two-thirds they outcrop as outliers among the pre-Cambrian rocks. These Paleozoic rocks are Upper Cambrian and Early Ordovician in age. A section from the base up is as follows: Potsdam sandstone and conglomerate (Cambrian) 0–150 feet, followed by a possible unconformity, then deposition of white sandstone 100 (?) feet, Theresa dolomite and sandstone 50 feet, and Heuvelton white sandstone 10–25 feet in thickness, all of which are Saratogan or Ozarkian in age. The Heuvelton is followed by a disconformity and after this period of erosion the Ordovician (Beekmantown) represented by the Bucks Bridge mixed beds of dolomite and sandstone 50–75 feet in thickness, followed by an unconformity and above this unconformity the basal 30 feet of the Ogdensburg dolomite. These various formations are described in detail. The Heuvelton and all beds above it are fossiliferous, but the fossils are poorly preserved.

The Potsdam sandstone is thought to represent the residuum of insoluble material from deep and thorough weathering of pre-Cambrian gneiss and quartzite. The total absence of fossils, the undercut erosion in the Grenville quartzite at some of the contacts, the fine and even nature of the sand itself right up to the contacts suggest a wind-blown origin. The position, the tillite-like nature, and many other features of some of the basal beds of the Potsdam suggest glacial deposits but no striated pebbles were found. The late pre-Cambrian and Cambrian history of this region is thought to have been as follows: (1) peneplanation, then (2) uplift and further deep weathering under a moist and warm climate, next possibly (3) glaciation followed by (4) arid, cold, desert conditions, and finally (5) slow submergence and encroaching of sea from the northeast. The late Cambrian and early Ordovician record is one of intermittent submergence and elevation. From the history of the region to the north it is almost certain that Chazy, Black River, and Trenton seas covered this area but their deposits have all been removed by erosion with the possible exception of a local thin bed of Trenton limestone. By the end of the Mesozoic the general region had been reduced to a peneplain. This peneplained surface is recorded by the high land with a nearly even sky-line. This peneplain was elevated, dissected by Tertiary rivers, and before Pleistocene glaciation, wide flat areas were developed which record a late Tertiary peneplain. The author calls attention to the close resemblance between the Mesozoic, Tertiary, and recent history of the region and the late pre-Cambrian and Cambrian history as outlined above.

J. F. W.

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*The Pre-Cambrian Rocks of the Canton Quadrangle.* By JAMES C. MARTIN. New York State Museum Bulletin, No. 185. Albany, N.Y., 1916. Pp. 112, pls. 20, figs. 30, maps 1.

The Canton Quadrangle lies in northwestern New York State about 12 miles east of Ogdensburg on the St. Lawrence River and 30 miles east of the Thousand Islands region. The geology is very similar to that of the Adirondack Mountains while the physiography is that of a line of foothills which mark the approach of the rugged interior to the southeast.

The oldest rocks, Grenville sediments, are crystalline limestone, garnet gneiss, quartzite, quartz-schist, and various other siliceous and pyritous gneisses. Owing to intense post-Grenville deformation no good continuous sections of the sediments remain, but the probable thickness is somewhere about two or three miles. The various rock

types of the series are intimately interbanded and in many cases one type gradually grades into the other. The dark-colored bands and spots rich in silicate minerals, in the crystalline limestone, are thought to represent recrystallized sedimentary matter and not to be due to the introduction of silica, iron, or alumina from the gabbroic or granitic magmas. Although some of the metamorphic amphibolite is of igneous origin and younger than the Grenville sediments, most of the field evidence points to a sedimentary or contact metamorphic origin for the garnet gneiss and a large part of the amphibolite. The different varieties of garnet gneiss and amphibolite associated with the igneous contacts probably are due to the different phases of intensity in the contact action.

The post-Grenville pre-Cambrian rocks are gabbro-amphibolite and granite gneiss intrusives. Two noncomformable contacts and their mineralogical composition indicate that certain of the amphibolites are igneous. The abundant inclusions of Grenville sediments in these amphibolites indicate their post-Grenville age. These gabbro-amphibolites are intruded by a gray to pinkish red massive to gneissoid granite gneiss. In almost all cases, owing to the severe regional deformation, the original nature of the contacts between the various types of pre-Cambrian rocks of this region is obliterated and it is very hard to work out field relationships. Inclusions of gabbro-amphibolites in pegmatitic phases of the granite gneiss prove a later age for the granite. Also during the intrusion of the granite magma, the amphibolite inclusions broke under deformation while granite flowed, which shows that the amphibolite antedates the intrusion of the magma. However, in only a very few cases is there evidence that these amphibolite inclusions are igneous and not metamorphic Grenville sediments. The great abundance of these inclusions, and the apparent incompetency of granite contact alteration to account for so much, suggests that much of it was formed by the gabbro-amphibolite intrusions before the invasion of the granite magma.

The rocks are almost universally foliated and over the whole area the foliation dips toward the west or northwest. A huge sigmoid fold in the southern part of the area is described and diagrammed in detail. Many minor folds are described.

This is an interesting description and application of a number of important principles of pre-Cambrian geology, especially the methods of separating the sedimentary and contact metamorphic amphibolite from the igneous gabbro-amphibolite, and the determination of the younger age for the granite as compared with the gabbro-amphibolite.

J. F. W.

*Genesis of the Zinc Ores of Edwards District, St. Lawrence County, N.Y.* By C. H. SMYTH, JR. New York State Museum Bulletin, No. 201. Albany, N.Y., 1917. Pp. 39, pls. 12.

This report presents the results of laboratory studies of ore from the zinc deposits of the Edwards district, which is about 15 miles south of the Canton area described in Bulletin 185, reviewed above, and the geology of the two areas is very similar. The ore minerals are sphalerite, pyrite, and galena, and occur as fillings of narrow cracks or as replacements along shear zones in the Grenville crystalline limestone. The deposits are of the high-temperature type, and the sequence of mineral deposition is as follows: (1) diopside, tremolite, (2) pyrite, (3) sphalerite, (4) galena, (5) talc, (6) serpentine. This sequence of mineral deposition indicates changing conditions from intense-contact, metamorphic conditions to those normal for the depths involved and without outside agencies. At all stages during this transition from intense to moderate conditions calcite was subject to repeated solution and recrystallization.

The granite magmas which intrude the Grenville sediments are considered the source of the ore minerals and during the cooling of the magma, gases and solutions were given off which carried the sulphur and metals into the country rocks where they were precipitated. The wall rock of the sphalerite is always crystalline limestone while the typical pyrite ore is always in schist or gneiss. Also the pyrite ore is always rich in graphite while the zinc ore contains but little graphite. The typical pyrite ore contains but little sphalerite but the zinc ore contains considerable pyrite.

These deposits are compared with zinc deposits of other regions and especially with the contact zinc deposits of the Christiania district described by Goldschmidt. Excellent photomicrographs show clearly the various mineral relations described in detail in the text. This is a valuable contribution to the subject of contact metamorphic ore deposits.

J. F. W.

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*New Edition of Coal, Oil, Gas, Limestone, and Iron Ore Map.* West Virginia Geological Survey.

Thoroughly revised, showing oil and gas pools, many anticinal lines not heretofore shown, and also booklet giving the names and post-office addresses of all the principal coal-mining operators in West Virginia up to July 1, 1921. Scale, 8 miles to the inch. Price, folded in strong envelope and delivered by mail, $1.00. Remittances to West Virginia Geological Survey, Box 848, Morgantown, West Virginia.

*Detailed Report on Nicholas County.* By DAVID B. REGER. West Virginia Geological Survey, No. 31. 1921. 847 pages+xx pages of introductory matter; illustrated with 34 half-tone plates and 22 zinc etchings in the text, accompanied by a separate case of topographic and geologic maps.

Nicholas County contains the New River Coal Group, as also the Kanawha Group and the lower members of the Allegheny Series in its northern portion. This report contains a chapter on the "Paleontology of Nicholas County" and a short description of the chert deposits of West Virginia by Dr. W. Armstrong Price. Price, including case of maps, delivery charges paid by the Survey, $3.00. Extra copies of topographic map, 75 cents; of the geologic map, $1.00. Remittances to West Virginia Geological Survey, Box 848, Morgantown, West Virginia.

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*Geology and Mineral Deposits of a Part of Amherst Township, Quebec.* By M. E. WILSON. Memoir 113, Canadian Geological Survey, Ottawa, 1919. Pp. 54, figs. 3, pls. VII, maps 2.

This district is thirty miles north of the Ottawa River and almost equidistant from Montreal and Ottawa, and lies within the dissected southern border of the Laurentian Plateau. The presence of extensive deposits of kaolin near the southern part of Amherst Township is of considerable geological interest, because kaolin is commonly thought to be the product of surface-weathering and in Canada, for the most part, the deposits formed by surface-weathering have been removed by Pleistocene continental glaciation.

The oldest rocks of this region belong to the Grenville sedimentary series and consist of quartzite, garnet gneiss, and crystalline limestone. These sediments are intruded by the Buckingham series of basic igneous rocks (gabbro, pyroxene diorite, and pyroxene syenite). Both the foregoing series are intruded by batholithic masses of granite-syenite gneiss. Glacial drift and marine Champlain clay partially fill the depressions between the rock ridges.

The kaolin and graphite deposits of the district are described in detail. The kaolin occurs in an extensive zone of fracturing and faulting in the Grenville quartzite and garnet gneiss and has been brought in by solutions from either above or below and deposited along open fracture planes or by the replacement of the quartzite wall rock. Crystals of tourmaline, a mineral formed at high temperatures, in the kaolin and the nearby outcrops of granite-gneiss suggest a deep-seated origin for

the kaolin. The presence of oxidized and kaolinized garnet gneiss at a depth of 85 feet is equally suggestive of the derivation of the kaolin from a superficial source. A summary statement of these two hypotheses to explain the origin of kaolin deposits is given, but the writer has no definite basis for deciding between them. The shattered zone of quartzite in which the kaolin occurs has a known width of 1,000 feet and a length of 7,000 feet. This kaolinitic quartzite rock can be easily crushed and is suitable for making silica brick of the ganister type or the kaolin can be washed from the crushed material and the quartz used for silica sand.

North of the kaolin locality a number of graphite deposits have been opened along the contacts of pegmatite, pyroxene granite, syenite, and Grenville limestone. The ore consists of aggregates of orthoclase, wollastonite, diopside, scapolite, and graphite. These relations and associations of minerals indicate that this material was formed by the interaction of emanations from the igneous intrusions and the limestone.

J. F. W.

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*Map of the North Pacific.* By W. E. JOHNSON. U.S. Coast and Geodetic Survey, Map No. 3080, North Pacific Ocean; scale 1:20,000,000; dimensions 14 by 41 inches. Price 25 cents.

A new base map of the North Pacific Ocean on the transverse polyconic projection has been prepared by W. E. Johnson, Cartographer, of the U.S. Coast and Geodetic Survey of the Department of Commerce, and is now available for distribution. This system of projection was devised by Ferdinand Hassler, who was the organizer and first Superintendent of the U.S. Coast and Geodetic Survey. This projection was computed and constructed by C. H. Deetz, Cartographer, U.S. Coast and Geodetic Survey.

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*The Mogollon District, New Mexico.* By HENRY G. FERGUSON. Bulletin 715-L, United States Geological Survey, Government Printing Office, Washington, D.C., 1921. Pp. 34, pls. 6, figs. 2.

The Mogollon (Mo-go-yohn) or Cooney district lies in southwestern New Mexico, about fourteen miles from the Arizona line. The district was discovered in 1875, when James Cooney found rich silver-copper ores there. Since then the mines have yielded about $16,000,000 worth of ores (estimated to 1917).

The topography is generally very rugged, especially on the eastern edge of the district, which lies along the Mogollon Range. The rocks are

dominantly Tertiary lavas, with interbedded sandstones. Faulting is extensive, and the fault fissures have been mineralized. In Quaternary times erosion was great and thick gravels accumulated; the gravel deposition was followed by more faulting, the fault plane paralleling the present front of the range, with downthrow on the west. Renewed erosion followed this last orogeny. The Tertiary formations, chiefly igneous, reach 8,000 feet in thickness. The flows are chiefly andesites and rhyolites, though there are a few basaltic lavas. Of the total thickness mentioned, 6,400 feet are pyroclastics and flows; the remainder are stream-laid sediments. Erosional unconformities within the sequence are common. Intrusives are represented by dikes of rhyolite and basalt.

Structurally the area is affected by complex normal faults; two periods of faulting are recognized—one before, the other after, the deposition of the rival gravels. The former was far more widespread, and nearly all the fault fissures of this period are now the site of fissure veins trending roughly north-south or northwest-southeast; one of these—the most prominent—can be traced for a length of seven miles, and the fault involves a displacement of a thousand feet or so. The first faulting resulted in increase erosion and the development of mature topography; on the west slope of the region there was at this time a broad valley, which later became filled with gravel to a depth of several hundred feet. Then came the great fault that now defines the front of the range; this renewed erosion and initiated the present cycle with its higher flat benches and lower steep canyons.

The ore deposits of the region are all in veins closely connected with the faults. The richest are the small ones lying along the fault fissures that are distributive from the great seven-mile fault (Queen fault) mentioned above. Locally the mineralization shifts from the main fissure to minor fissures in the wall, indicating that mineralization was not contemporaneous with the faulting. The mineral content of the veins includes quartz, calcite, a little adularia, and flourite (locally plentiful). Argentite, with small amounts of associated pyrite, chalcopyrite, bornite, galena, and sphalerite are the metaliferous primary minerals; in a few veins copper minerals—bornite, chalcopyrite, chalcocite, and tetrahedrite—predominate. Quartz and calcite are the chief gangue constituents. Oxidation is shallow and irregular. Sulphide enrichment appears to have been somewhat effective. The oxidized ore bears cerargyrite, native silver and gold, basic copper carbonates, limonite, copper pitch ore, cuprite, and manganese oxides. Chalcocite,

covellite, some argentite, pyrite, and native silver are probably due to sulphide enrichment, but a part of the argentite and pyrite and all of the bornite, chalcopyrite, tetrahedrite, and galena are apparently primary.

Quartz was the first mineral to be deposited and it was followed at once or even accompanied by the greater part of the sulphides. The later stages of vein-filling were marked by coarsely crystalline calcite, largely manganiferous and barren of sulphides. Mineralization of the wall rock is not prominent; in andesites, pyrite has penetrated the rock for short distances from the veins, or the rock is cut by veinlets of quartz, calcite, and copper sulphides. The dark silicates in the andesites are often almost completely altered, and calcitization is common. The rhyolitic country rock near the veins shows some secondary silicification, and the feldspars are frequently replaced by quartz with an apparent decrease of volume.

Although the oxidation zone is generally shallow, it may extend to the 500- or 700-foot levels. Argentite appears here and there as filling in minute cracks, apparently later than the veins, and pyrite clearly of later origin is seen in fissures in the quartz. No sulph-arsenic or sulph-antimony salts of silver, such as commonly characterize many sulphide enrichment zones, are found, but chalcocite and a small amount of covellite do attest the effectiveness of some enriching action. Probably sulphide enrichment is appreciably active only where unusually favorable conditions, such as later faulting, were present. The ground water-level lies very deep and the mines are dry, except along the Queen fault.

The ore shoots are 300 to 600 feet in drift length and about as long parallel to the dip, with widths averaging 5 to 15 feet. They tend to show flat bottoms, which is thought by the investigator to be suggestive of enrichment.

The peculiar localization of the productive veins within a small district not over one square mile in extent is attributed to the faulting, which only produced the throw necessary to bring the ore within reach of the surface over a very small area; greater or lesser throws either resulted in too deep an erosion or in the exposure of the barren low-temperature manganiferous-calcite veins.

The important mines are the Cooney, Little Fanney, and Last Chance; the last being the largest. In the past twenty-five years the Last Chance mine has yielded about $7,500,000, worth of ore. The metals obtained are gold and especially silver, and a high-grade ore lies close to $20 a ton in value.

C. H. B., Jr.

*Tungsten in 1918.* By FRANK L. HESS. From "Mineral Resources of the United States," (United States Geological Survey), 1918. Part I, pp. 973–1026; Government Printing Office, Washington, D.C. Pp. 53; with summary of recent publications.

The years 1916, 1917, and 1918 recorded the largest production of tungsten ores which this country has known, about 5,000 or 6,000 short tons for each of these years as compared with a maximum around 2,000 tons in previous years. Slightly over 50 per cent of the 1918 output was scheelite from California and Nevada, and nearly 40 per cent was ferberite from Colorado. Preliminary figures for 1919 and 1920 issued by the United States Geological Survey show a slump in production to around 200 to 300 tons, figures lower than any recorded since 1903 and due to the depression in the steel industry which is the principal tungsten consumer.

No fully satisfactory substitute for tungsten in tool-steel has been developed. To quote Mr. Hess: "It is said that in England and France molybdenum has been used to replace about half of the tungsten in some high-speed tool-steels, but it is apparently not a preferred metal, being used only when it is difficult to obtain tungsten."

In California and in Nevada scheelite is found mainly in contact metamorphic deposits in limestone near granitic intrusives. In South Dakota the production was mainly wolframite from replacement deposits in dolomite near Lead and Deadwood. The chief competitor for the American market is China, where the discovery of great, easily worked placers in the southern provinces has been the most striking event of recent years in tungsten geology.

A brief summary of the international situation shows that Great Britain controlled and imported, in 1918, 33.7 per cent of the world's output, and thus owned by far the greater part of the 1918 production.

Another interesting fact in regard to tungsten minerals is their rather general limitation in economically important deposits (with the exception of those on the Iberian Peninsula) to areas closely contiguous to the Pacific Ocean—a good illustration of the provincial character of metallic distribution, which may perhaps be correlated with the petrographic provinces as pointed out by Alfred Harker.

The paper presents an excellent and much-needed summary of the tungsten situation, treated both from the geological and economic point of view, and closes with a summary of recent literature on tungsten.

E. S. B. AND C. H. B., JR.

*Geology of the Matachewan District, Northern Ontario.* By H. C. COOKE, Memoir 115, Canada Department of Mines, Geological Survey, Ottawa, 1919. Pp. 60 (including index), with map, figs. 5.

The area described lies in the district of Timiskaming and includes about 430 square miles. Topographically two elements are recognizable —first, pre-glacial erosion, chiefly of the Cobalt series, which frequently outlines structural features in the pre-Cambrian rocks, and second, drift features, changing with the character of glacial erosion and deposition. The bed rocks are entirely pre-Cambrian, ranging from Keewatin (?) to Keweenawan. The Keewatin (?) rocks are volcanics—extrusives, for the most part, but with small masses of peridotite intrusive into them. The peridotites may prove to be of commercial importance, since asbestos of good quality has been found in them; the rock is highly metamorphosed—kaolinized, or altered to talc, or sericitized. The rhyolites are slightly less quartzose than those of northern Quebec, and the basalts of the Keewatin frequently show pillow structure. All these rocks are highly altered and closely folded and faulted, the folding probably following the deposition of the overlying Kiask series which are dominantly metasedimentaries of many types. From their character, it is thought that the Kiask sediments were laid down rapidly, without much weathering, on an uneven surface.

Kiask sedimentation was succeeded by granitic intrusions and later by a period of basic intrusion, marked by diabase dikes. The overlying Cobalt series is divided into the Gowganda formation (basal conglomerates and very coarse clastics) and the Lorraine quartzite, following Collins. Faulting and some gently folding have been developed here also.

Deposits of asbestos and small deposits of barite, fluorite, and hematite have been found. The asbestos occurs as veinlets in small masses of serpentinized peridotite. The barite, fluorite, and hematite occur in veins. By far the most important mineral however is gold, which has been known in this district since 1917. The gold is closely associated with intrusive granite porphyry; solutions thought to have come from the granite porphyry magma have mineralized the volcanic country rock with the deposition of auriferous pyrite. The gold is in narrow veins of quartz intersecting the granite porphyry or in lenticular ore bodies in the tuff and schist, varying in size up to 75 feet, with their long dimensions parallel to the bedding planes of the tuff and schists.

A geologic map makes the work complete, but the absence upon it of topographic contours is regrettable.

C. H. B., JR.